Control ENGINEERING

INSTRUMENTATION AND AUTOMATIC CONTROL SYSTEMS

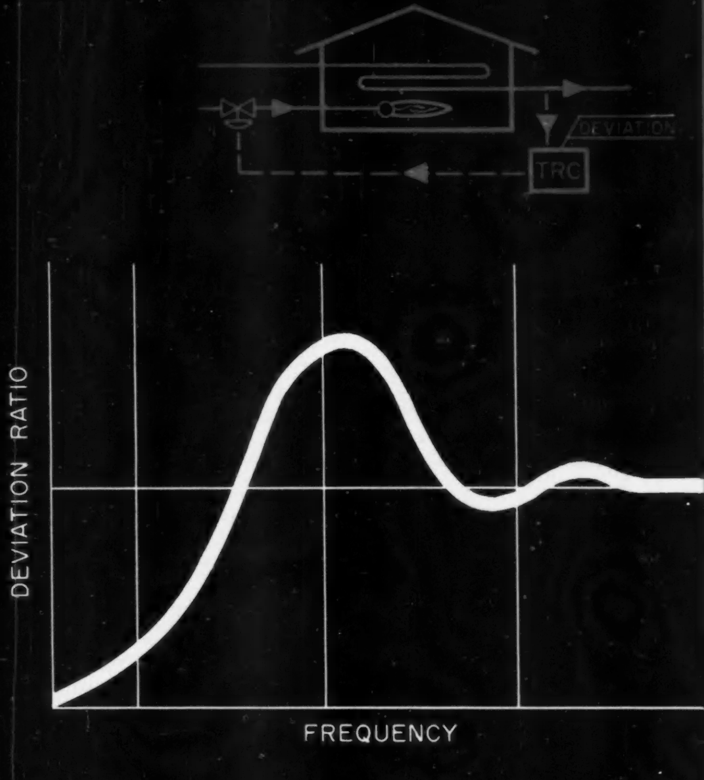
A McGRAW-HILL PUBLICATION

PRICE 50 CENTS

NOVEMBER 1955

PLANT CONTROLLABILITY:

by analyzing a plant's Deviation Ratio you can determine how to select the best controller system



ALSO IN THIS ISSUE:

Design by Error Coefficients

Color Instrument Fundamentals

Basic Digital Series—No. 2: Methodical Number Systems

Flexibility in Application
Versatility in design...

packaged analog-digital converters

Shaft Position to Digital Converters features reliability, long life, non-ambiguity and speed makes these converters ideal for computers or data handling systems where serial read-out is preferred. Librascope converters transmit information at almost any rate desired up to 1 mc and in some cases above, and may be multiple time-shared, holding extra circuitry to a minimum. All units quickly adjustable, syncro-mounted. Available in Binary, Gray code or Binary decimal code as shown in chart below. Special units may be designed to your order.

Write for catalog information.

FEATURES:

- Unique, staggered double brush pick-off system.
- Reads out serially into relays or single or multiple scan matrices.
- Analog-digital or digital-analog operation.
- May be time-shared.
- Syncro-mounted.
- Associated circuitry can be designed to fit your data-handling problems.

CODE	MODEL*	RESOLUTION PER INPUT SHAFT REV.	RESOLUTION OVER FULL RANGE	DIMENSIONS DIAMETER X LENGTH
BINARY	7 digit	128	1 part in 128	2"x2 49/64"
	13 digit	128	1 part in 8192	2"x3 19/32"
	17 digit	128	1 part in 131,072	2"x4 13/16"
	19 digit	128	1 part in 524,288	2"x4 13/16"
BINARY CODED DECIMAL	0-2000	200	1 part in 2000	3 1/16"x4 27/32"
	0-3600	200	1 part in 3600	3 1/16"x4 27/32"
	0-20,000	200	1 part in 20,000	3 1/16"x4 27/32"
	0-36,000	200	1 part in 36,000	3 1/16"x6 3/8"
GRAY	8	256	1 part in 256	3 1/16"x1 11/16"
*SPECIAL UNITS AVAILABLE	**Precision gearing** **Shaft Speed:** 120 rpm continuous **Operating temp:** —55° C to +75° C **Shock and Vibration:** up to 15 G, 5 to 500 cps.		**Life Expectancy:** Function of lead current. For 13 digit unit @ 2 ma. per brush, life approx. 5x10^{8} breaks or makes at approx. 120 rpm.	

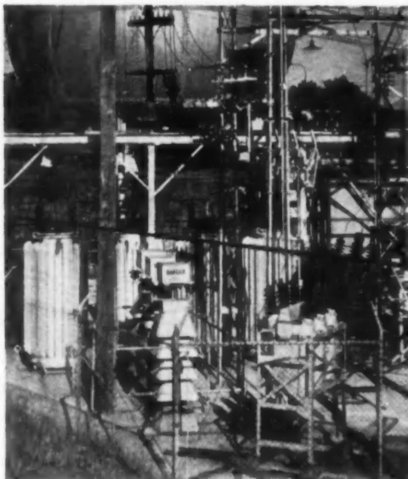
Engineers, physicists and mathematicians interested in challenging California careers, contact Mac McKeague, Personnel Director.

LIBRASCOPE

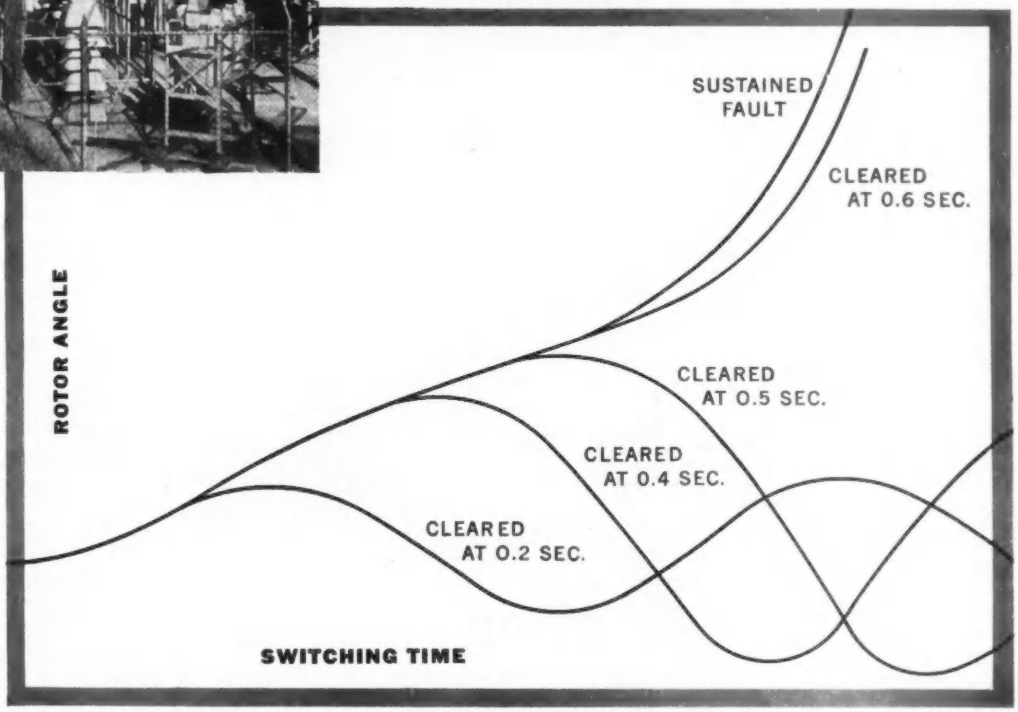
A SUBSIDIARY OF GENERAL PRECISION EQUIPMENT CORPORATION

COMPUTERS, COMPONENTS AND CONTROLS.

LIBRASCOPE, INC. • 808 WESTERN AVENUE • GLENDALE, CALIFORNIA



GEDA
solves control problems
for example:



How long can a breaker take to break?

When a short circuit occurs on a power system, a circuit breaker goes into operation—opening or "clearing" the fault while protecting the generator. However, the circuit breaker requires a certain amount of time to operate. If the time is too long, the generator will slow down until it gets "out of step" with the rest of the system.

The power system swing curves shown above illustrate what happens to system stability as the time lag increases. This problem of the electric power industry *and countless other problems of analysis and control in other industries*—possibly in yours—are quickly and easily solved with GEDA, the Goodyear Electronic Differential Analyzer.

The Versatile Analog Computer of Advanced Design, GEDA can deliver to you tremendous savings in engineering man-hours—eliminate empirical guesswork and costly experimentation.

Its quality and flexibility is equalled only by its ease of operation. Programming is simple; results are shown in wave forms and voltages—require no specialized mathematics to translate them.

Write for full information on the complete line of GEDA Advanced Design Computing Equipment, a product of Goodyear Aircraft Corporation, Dept. 931GK, Akron 15, Ohio.

GEDA *ANALOG COMPUTERS—best way to give your hunch a chance!*

GEDA—T. M. Goodyear Aircraft Corporation, Akron 15, Ohio

GOODYEAR AIRCRAFT

Control ENGINEERING

NOVEMBER 1955

INSTRUMENTATION AND AUTOMATIC CONTROL SYSTEMS

FEATURE ARTICLES

IDEAS AT WORK

DEPARTMENTS

WILLIAM E. VANNAH	Editor
LLOYD E. SLATER	Managing Editor
BYRON K. LEDGERWOOD	Associate Editor
EDWARD J. KOMPASS	Assistant Editor
RAYMOND N. AUGER	Assistant Editor
HARRY R. KARP	Assistant Editor
WARREN KAYES	Copy Editor
FLORENCE BAXLEY	Editorial Assistant
JACK GORDON	Art Director
DEXTER M. KEEZER	Dir. Economics Dept.
G. B. BRYANT, JR.	Mgr. Washington Bureau
JOHN WILHELM	Editor, World News
SEABROOK HULL	London

Consulting Editors

GORDON S. BROWN	Cambridge, Mass.
EUGENE M. GRABBE	Los Angeles, Calif.
MARION V. LONG	Emeryville, Calif.
KEITH HENNEY	New York, N. Y.

Advertising Sales

ROBERT W. OBENOUR	New York
GEORGE S. BAIRD JR.	Boston
W. F. BUEHL	Philadelphia, New York
JOHN C. MITCHELL	Cleveland, Detroit
JOHN G. ZISCH	Chicago, St. Louis
STOKES T. HENRY	Atlanta
JAMES H. CASH	Dallas
T. H. CARMODY	San Francisco
GORDON L. JONES	Los Angeles

W. W. GAREY	Publisher
R. M. H. BERG	Advertising Sales Manager
W. C. CARMICHAEL	Production Manager

ABC

ABP

PRINT ORDER THIS ISSUE 28,274

SHOPTALK

TIME, TACT, TENACITY—AND KARP

If we were to sum up in three words what it takes to get a good article into print, we'd say: time, tenacity, and tact. Consider J. M. L. Janssen's article on page 58. Our European traveler solicited it in 1954 and the manuscript came to us via Shell Development's U. S. Lab in California last spring. The contents of the raw ms. were superb, but its language was rather esoteric. Our problem was to make the dish palatable for 25,000. We assigned the editing job to Harry Karp, who claimed, "If I can understand my edited version, the reader will too." For background, tenacious Harry visited Russ Aikman at Schlumberger Instrument in Connecticut. Russ, a former Englishman who knows Janssen and his objectives, supplied practical examples for the article. Harry sent the revision—interpreted, reorganized, and trimmed—to Janssen with a note tactfully explaining his rigorous editing, then braced for a wrathful withdrawal of the article. Instead, from Holland came a resounding "splendid" and from U. S. Shell a rather amazed "well done".

REPRINTS, ANYONE?

A few months ago in this column we mentioned that we were considering reproducing the complete editorial material in out-of-print issues. Several subscribers wrote in, asking for these articles. But if we are to reissue them without going broke we'll have to have at least 200 requests for each CtE number. This would bring the price to somewhere around $1.00 per issue. If you are interested send a note to Mrs. Florence Baxley, who took over when Sue Richmond left for Europe.

JOHN GETS HIS MAN

Our *Control Personality* this month was selected for us well before our first issue was out. Selected by John Zisch, that is. John, our Chicago district manager, came to the new-born CtE direct from the Comptroller's desk at J. B. Rea Co. His first words to the editors consisted of a glowing report on the J. B. Rea Co. in general and on J. B. Rea in particular. He has never let up. So we recently made a point of meeting Jim. The sketch on page 15 proves John was not exaggerating.

FEEDBACK

Disturbance . . .

To the Editor—

May I call your attention to an error I noticed while reading your very instructive magazine, Control Engineering. On page 79 of the July issue, the authors have normalized their equations and then incorrectly used the plot of valve characteristics when they inserted in the equations values for an example.

Hans Scheunn
Campbell Soup Co.
Camden, N. J.

. . . and response

We sent Mr. Scheunn's thorough critique to the authors of the article. Here is the reply from the senior author. Ed.

To the Editor—

We have reviewed the comments and found that Mr. Scheunn is correct. A numerical error was made by the authors which, fortunately, does not effect the Bode plots or the economics discussed.

The valve constants on page 79 of the article are numerically incorrect. Each should be multiplied by 0.257. In connection with this, the following corrections should be noted.

1. On page 77, Equation 1: replace f_v by F_o.
2. On page 78, replace f_v by F_o in three places:

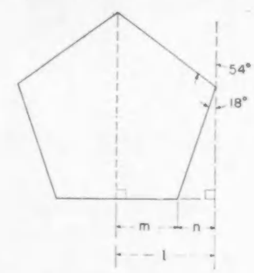
"F_o = a function of pressure ratio."
"$w_e = f(a, p_1, \theta, F_o)$"
"and since F_o is a function of the pressure ratio."

Other corrections:

. . .

THIS MONTH—A PIQUE INSTEAD OF A PROBLEM

Control engineers look for diversion in many ways and places. Some play Canasta or Monte Carlo or seriously study game theory as a professional practice and/or hobby. Here is a short essay on geometrical relationships that may pique your interest. Ed.



From 15-place tables:

sin 18° = 0.30901, 69943, 74947
sin 54° = 0.80901, 69943, 74947

One would suspect that the sixteenth place might agree, and it does. We tried unsuccessfully to prove the tables with various identities until Morton Mathew (Ahrendt Instrument Co.) finally appealed to Euclid. I don't think the proof is too obvious.

consider equilateral pentagon having sides of unit length.

$$m + n = l$$

also

$$n = \sin 18^\circ$$
$$l = \sin 54^\circ$$
$$m = \tfrac{1}{2} \text{ (by symmetry)}$$
$$\sin 18^\circ + \tfrac{1}{2} = \sin 54^\circ$$

The same type of reasoning can be applied to give other integral angle values having precise relationships for 9- and 15-sided figures (or more generally, odd numbers which divide integrally into 360 deg without remainder).

Frank Bradley
New York, N. Y.

NOVEMBER 1955 Control Engineering VOL. 2, NO. 11

Published monthly by the McGraw-Hill Publishing Co., Inc., Executive, Editorial, Advertising and Subscription Offices: **McGraw-Hill Building, 330 West 42nd Street, N. Y. 36, N. Y.** Publication Office, 99-129 North Broadway, Albany 1, N. Y.; entered as second class matter at the Post Office at Albany, N. Y. Donald C. McGraw, president; Paul Montgomery, executive vice-president; Joseph A. Gerardi, vice-president and treasurer; John J. Cooke, secretary; Nelson Bond, executive vice-president, Publication Division. Ralph B. Smith, vice-president and editorial director; J. E. Blackburn, Jr., vice-president and circulation director; Joseph H. Allen, advertising director. **FOR SUBSCRIPTIONS**, write to: Control Engineering-Subscription Service, 330 West 42nd Street, New York 36, N. Y. Orders must indicate company and position. Allow one month for change of address. Single copies 50¢. United States and possessions: $3 for one year, $4 for two years, $5 for three years. Canada: $4 for one year, $6 for two years, $8 for three years. Latin America: $10 for one year, $16 for two years, $20 for three years. Other countries: $15 for one year, $25 for two years, $30 for three years. Printed in U.S.A.

3. On page 78, delete the two lines following Equation 3.

4. On page 78, bottom of first column: "A plot of $F_o/0.257$ versus $\frac{P_{2o}}{P_{1o}}$ is shown."

5. On page 74, Equation 34:

$K_4 = 2420(0.257) = 623.5$

The numerical value of K_{11} must still be such as to make K_4, K_v, K_q, K_{11}, $K_m = m/144$
i.e., K_{11} would be larger by the factor 1/0.257.

We regret that this numerical error occurred in the article and we appreciate your calling it to our attention.

George J. Fiedler
Principal Engineer
Controls and Instrumentation
Sverdrup & Parcel, Inc.
St. Louis, Mo.

But . . .

TO THE EDITOR—

In *These 7 Steps Design a Tach Stabilized Servo* (CONTROL ENGINEERING, Vol. 2, No. 8, August 1955), Jules E. Kadish nicely synthesizes positional servos. The components and system, taken in the example, ably illustrate the error-reducing virtue of a two-speed data or error detector technique but unfortunately leave the impression that the extra weight and complexity of two-speed synchro systems are musts if positional accuracy of ½ deg is to be realized.

The plus or minus ½ deg error value attributed to the Eclipse-Pioneer transmitter-control-transformer combination is not normal servo error but is rather a catalog value for maximum error spread. Chosen by the author, these synchros, properly aligned in the mechanism, should contribute only ¼ deg (max) error to the servo system, leaving ¼ deg "margin for following errors and other inaccuracies".

Even more error margin is available since in reality several probabilities that favor the servo designers are also at play: (1) the probable error spread for a synchro system consisting of a randomly combined transmitter and control transformer runs considerably less than the arithmetic sum of the two individual error spreads; and (2), less than 10 per cent of the units delivered by reputable manufacturers have error spreads ex-

ceeding 80 per cent of the published limit. The error spread of the average unit is around 65 per cent of the applicable spec limit.

If the servo designer dislikes these probabilities, he may elect to use the calibration error data furnished by the manufacturer with each unit and make the preferred inter-synchro lead connections, thereby most favorably phasing the error of, say, the control transformer relative to individual transmitters. This practice yields a resultant synchro error spread that is rarely larger than that of the worst individual unit in the synchro system.

Another approach for the servo builder is to buy more precise synchros in the first place. Within the allowable size (15) and weight (5 oz per unit), units are available in production with 5 and 10 min factory error spread guarantees which, ignoring combination probabilities, still yield peak synchro system errors of less than 0.15 deg.

A single-speed synchro system with even higher accuracy is readily available to those who use a transmitter with a 5 min catalog error spread and connect it electrically to a control transformer, though it is sometimes shipped "flat" to the servo builder who adjusts it according to the nonlinearities of the input transducer or his other desires.

Finally, those needing the absolute accuracy realized by two-speed synchro techniques often face space and weight problems, which they minimize by choosing synchros that weigh 1.1 oz (Size 8) or 1.8 oz (Size 10) instead of 5 oz (Size 15).

Arnold E. Hayes
Service Engineer
Clifton Precision Products Co., Inc.
Clifton Heights, N. J.

. . . and Rebut

To the Editor—

I have just read with considerable interest the letter written to you by Arnold E. Hayes of Clifton Precision Products Co., referring to the tach stabilized servo article in Control Engineering.

This article was originally written to aid people within our group at AMF who were concerned with synthesizing these types of servos, but who had relatively little background in the field. Consequently, the example given had to emphasize the technique of designing a two-speed data system, rather than the fundamental detail of its accuracy. Mr. Hayes is entirely correct in indicating that the ½ deg error value attributed to the Eclipse Pioneer Synchro combination is incorrect. Our experience

has also been that the error of the combination is much closer to that of a single synchro.

The use of more precise synchros or a synchro with an adjustable cam must certainly be considered when designing positional servos whose accuracy requirements are stringent.

One other factor, not mentioned by Mr. Hayes, which may favor a two-speed system, is that the coarse synchro in such a system may have more backlash between it and the motor shaft than the fine synchro. Hence, servo stability is somewhat facilitated by the use of a two-speed system.

In any case, the suggestions of Mr. Hayes are well taken and are certainly applicable.

J. E. Kadish
Electronics Division
American Machine & Foundry Co.
Boston, Mass.

ISA takes the initiative

To the Editor—

Standardization of electrical signals, instrument connections, and controllers for industrial application have had our attention for some time. As you know, a standardization of pneumatic signals has been accomplished through combined efforts of our Recommended Practices Committee and SAMA. The question of electrical signal standardization has come up in our recent user-manufacturer meeting. At present the major manufacturers are not together in their electrical signal output. This question is presently being discussed with SAMA in connection with possible action. As yet, we have not formalized a committee to do anything on this subject, but are looking to SAMA for action on this particular problem.

As for connectors for transmitters and controllers, this is very definitely on our agenda. We are on record to SAMA with recommended markings and connection orientation for transmitters and controllers.

In several of these problems, the Recommended Practices Committee has taken the initiative as a coordinator with other groups such as the Steam Specialties Club and SAMA. Our committee has active liaison with ASME, SAMA, and other groups. We are definitely interested in this type of work and feel that we will

NEW 17 POUNDS OF PRECISION:

DU MONT TYPE 331
CATHODE-RAY OSCILLOGRAPH

- Developed in close cooperation with a leading manufacturer of computers
- DC to 4 mc vertical bandwidth (Transient response, 0.08 μsec)
- Precise measurement of time intervals (from 2.5 seconds to 0.08 μsec)
- Accurate voltage calibration over range from 0.4 to 400 volts full scale
- Flat-face, tight-tolerance Du Mont Type 3WP- Cathode-ray Tube provides excellent deflection linearity and freedom from field distortions
- Three-times undistorted sweep expansion of *any* calibrated sweep. Any expanded portion may be positioned on screen

ADDITIONAL FEATURES

Illuminated calibrated scale
High impedance test probe supplied
May be continuously operated horizontally or vertically
Beam-gate output at front panel for triggering external devices
Swing-away chassis construction assures accessibility of all components for convenient maintenance
Probe, instruction manual, and other accessories stored in front panel cover

***AND BEST OF ALL, THE PRICE IS ONLY* $585**

Never before has so much high-quality performance been compressed into so small a package. Here, in well under a cubic foot, (7⅞" x 9" x 17½") are *complete* facilities for high-precision observation and measurement of signals from d-c to 4 mc and beyond.

With its wide-band features and excellent pulse response (0.08 μsec) the Type 331 is particularly well suited for maintenance of computers and radar systems, or wherever portability—without sacrifice in performance—is required.

And in this day of cluttered work benches, the compact design of the Type 331 means that for general applications, you have laboratory performance in half to a quarter the surface area occupied by other instruments of comparable function.

For complete details, write to the address below for the technical bulletin.

IMPORTANT SPECIFICATIONS

Cathode-ray Tube: Type 3WP.

Deflection Factor: (full gain) a-c or d-c input, 0.2 p-p volts full scale (1.8").

Frequency Response: (any control setting) flat from d-c to down not more than 30% at 4 mc.

Calibrated Sweeps: 0.5 second to 0.5 μsec per major scale division (0.45"); expansion of 3X available on all ranges.

Amplitude Measurement: 0.4 to 400 volts full scale in 7 ranges.

Size: 7⅞" x 9" x 19½" overall including cover; weight without cover, 17½ lbs.; with cover 19¼ lbs.

DU MONT

TECHNICAL SALES DEPARTMENT • ALLEN B. DUMONT LABORATORIES, INC.
760 BLOOMFIELD AVENUE, CLIFTON, N. J.

FEEDBACK

be successful in accomplishing these goals. The most difficult one is that of electrical signal standardization. If you have any suggestions along this line, we certainly would appreciate your comments.

A. V. Novak, *Chairman*
ISA Recommended Practices Committee
Orange, Texas

Readers, what suggestions have you? Send them in and we will gladly pass them on to interested societies and trade associations. Ed.

Successful enterprise

Thanks for the article, *Monitors Safeguard Industry's Processes*, in the September issue of CONTROL ENGINEERING.

It seems to me that this is a real service to your members. Anybody in the market for monitoring equipment can find in this article the information needed to judge the merits and limitations of each system. I found the contents quite unbiased.

I am ordering several hundred reprints to spread the idea that monitoring (not just ours) has come of age and that it is doing a necessary job in industry.

Albert B. Poe
Thomas A. Edison
West Orange, N. J.

Positive feedback to our enterprise will prod the editors to publish similar surveys on other components and sub-systems available to our field. Ed.

Out-of-print issues

TO THE EDITOR—

I have now received three issues of your magazine and have thoroughly enjoyed each of them.

In your August 1955 issue, in *Shoptalk* (page 4), you queried whether any of your subscribers would be interested in complete back issues now out of print. I, for one, would certainly be interested in obtaining a publication of this type.

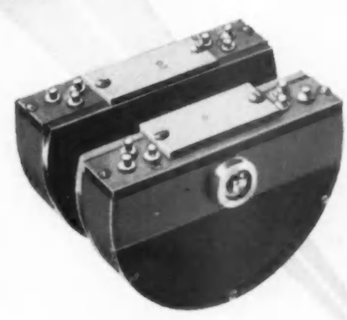
Peter J. Greisen
Elmsford, N. Y.

We continually receive requests for issues that appeared before readers entered their subscriptions. If we receive enough requests we may be able to reproduce back issues at a price that will not ruin the reader's budget. Let us know your pleasure. Ed.

Need a special potentiometer design? Our engineers are specialists in designing sub-miniature potentiometers, sector and open card winding potentiometers, and other combinations of special factors and functions. As the leader in standard precision potentiometer production, Fairchild has all the advanced techniques and facilities to give you fast service on both test models and production runs of potentiometers built to your exacting requirements.

SPECIAL POTENTIOMETERS

for your special needs



This is a special sector potentiometer. It came into being when the Eclipse-Pioneer Division of the Bendix Aviation Corporation needed a potentiometer with gear drive to mount within limited space in the altitude compensator of their Beam Guidance System. Excessive torque would cause inaccurate readings and result in unsatisfactory operation of the system, so a potentiometer with minimum torque was necessary. Since space limitations dictated an unusual configuration, our engineers worked with Eclipse-Pioneer engineers to develop this special design. The critical torque requirements of 0.075 oz.-in. on a 4 gang unit were met by specially designed wipers, windings, and slip rings. This same constructive cooperation can help you when you need a special or a standard potentiometer. So, call Fairchild first. Potentiometer Division, Fairchild Controls Corp., a subsidiary of Fairchild Camera & Instrument Corp., 225 Park Ave., Hicksville, N. Y., Dept. 140-67C.

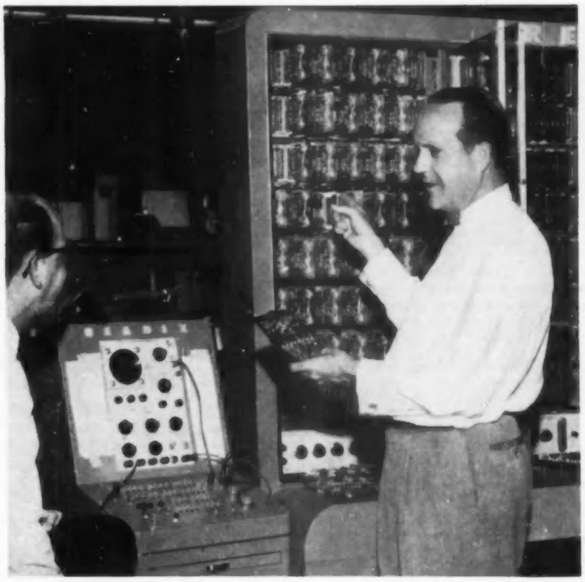
EAST COAST	WEST COAST
225 Park Avenue	6111 E. Washington Blvd.
Hicksville, L. I., N. Y.	Los Angeles, Cal.

FAIRCHILD
PRECISION POTENTIOMETERS

JIM REA
grounds himself in control

Some years ago the work of Dr. Stark Draper of MIT moved a young music and math major at Berkeley to sell his small plane and the dance band that paid for it and hitchhike to Boston.

For Jim Rea—who acts just as decisively today—this stint for a Master's was his first grounding in the basics of automatic control. After a few busy years as a PanAm flight officer and Consolidated Vultee chief test pilot, Jim grounded himself again. But this time he went to Boston in style—on a Convair scholarship. Then back into the air went Dr. Rea. But in 1951—after 12 years aloft, with schoolbench landings—Jim decided he'd been "up in the air" long enough. Down he came to team a pilot's intuition with a knowledge of control technology as head of Douglas's dynamic systems analysis section, which meant work on the Sparrow and Nike. And to leave shortly to form the J. B. Rea Company, which was to become one of the most vigorous systems engineering organizations on a notably vigorous West Coast.



Jim Rea replaces a diode plug-in board in the Rea Company's Readix decimal computer as he and Project Engineer Dick Russell check over the computer's static test panel.

He came by his control "instincts" naturally

Jim's feeling for control systems engineering was nurtured midst the cane and pineapple fields near Honolulu, where he was born in 1916. His father, a civil engineer who had learned navigation on New England sailing ships, steeped him in differential and integral calculus before Jim went to high school. From his mother, a music teacher, he acquired a musical background. For Jim Rea the two interests melded neatly: "Why not," he theorized, "apply mathematics to musical composition?" It's a theory he still tinkers with, and which he claims he will one day run through a computer "just to see what happens."

During his first hitch at MIT Jim Rea focused on Aeronautical Engineering and he went into commercial piloting with an unusual grasp of the components that form the aircraft system. And his concept of controlled flight resulted in a series of articles on navigation and long range cruise control that are still used as standard procedure by many airlines. Back at MIT for his Doctorate, he not only took up where he left off, but tackled the new field of jet propulsion. His interest in automatic control, however, was further fired by Stark Draper, and after passing all examinations in jet propulsion and power-plant engineering, Jim did a complete switch and wrote his thesis on "Automatic Tracking and Fire Control Systems", which was promptly classified by the military. Dr. J. B. Rea was well-launched into a pioneering career in control systems of engineering.

He applies dynamic analysis to surfboarding

At 39, Jim is an active sportsman. He, his wife Frances, and their four children often pile into the family station wagon for a day of surf-riding off Malibu point near the company's handsome Santa Monica plant. But for thrills more reminiscent of his years in bumpy skies, Jim Rea jaunts to Rincon Point near Carpenteria, Calif., where his instinctive feel for dynamic analysis goes to work in keeping him erect and intact on the famous storm surf. If he ever finds time, he says, he'd like to return to the islands to apply this talent to the thirty-foot waves surging in at Makaka beach.

Vapor Pressure Bellows Devices for Remote Control of Temperature

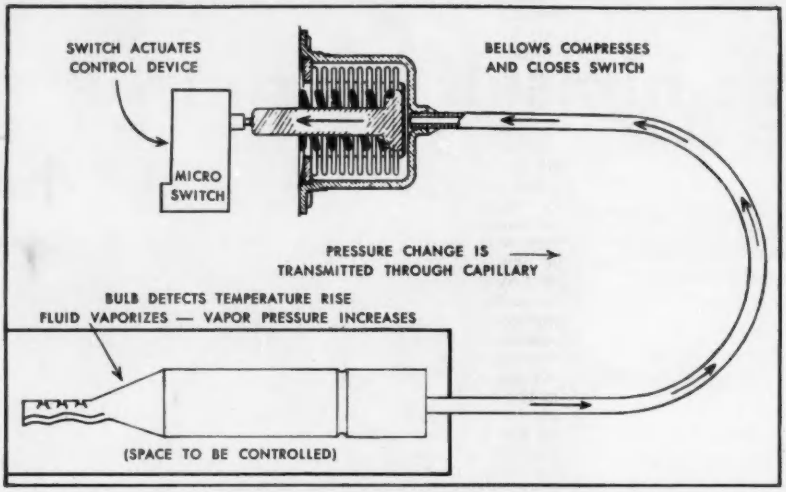


Figure 1. Vapor pressure bellows assemblies provide remote temperature control over a temperature range from about −40F to a maximum of 500F, depending on the vapor pressure of the filling medium at the maximum temperature encountered. They offer the advantage of high sensitivity and relatively long bellows stroke. This principle may be applied using increase or decrease of the vapor pressure to transmit the force to actuate a control mechanism.

ADVANTAGES OF VAPOR PRESSURE CONTROLS

Vapor pressure bellows assemblies offer a number of advantages in temperature control applications. They are highly sensitive and provide very close temperature control. They are positive-acting, simple in operation and easy to install. They can be made "fail-safe" to protect the equipment to which they are applied. When spring loaded, vapor pressure assemblies can be adjusted within very close limits. Bellows stroke is relatively long, making it easy to actuate switches or valves without elaborate linkage. They can be used for temperatures as low as −40F or as high as 500F and not affected by ambient temperatures outside of the chamber to be controlled. As a result, vapor pressure bellows assemblies are widely used as temperature controls for refrigerators, ovens, appliances, hot water storage tanks, processing equipment, wax pots, acid baths and numerous specialized industrial applications.

Proved in use. Vapor pressure bellows systems have long been used as temperature controls. Hence, a large body of performance and design data has been accumulated. This data assures accurate prediction of performance of a vapor pressure assembly, given the conditions under which the system will operate. And, since the design considerations are well known, it is usually simple to design a vapor pressure bellows assembly that will meet service requirements satisfactorily. The Clifford Manufacturing Company has a broad range of standard thermostatic assemblies engineered for quality, economy and reliable operation. These can be furnished to meet a wide variety of temperature control applications or readily adapted in design to meet special requirements. Important savings can be achieved by utilizing a standard design. A sketch showing controlling factors and dimensions for your application will enable Clifford to advise you how a standard design will meet your requirements.

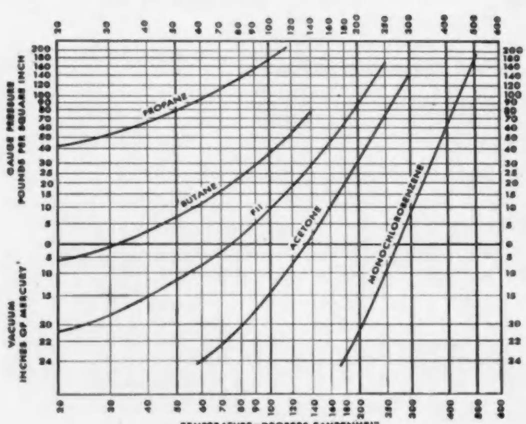


Figure 2. Vapor pressure-temperature curves for a few of the more common fluids used in vapor pressure bellows assemblies.

Operating principle (Fig. 1). When a confined liquid is heated, a vapor pressure is generated in the space above it. Vapor pressure as a function of temperature varies according to definite laws and so may be predicted accurately (see curves, Fig. 2).

Vapor pressure increases in an exponential curve. Butane, for example, from 30F to 40F changes pressure only 3 psi, but from 90F to 100F changes 9 psi. Therefore, a switch that operates with a .010 movement would have ⅓ the *temperature* differential at the higher end of the curve than a control operating at the low end of the curve.

The thermal fluid is stored in a temperature sensing bulb which is placed in the space to be controlled. The bulb is connected to a bellows cup assembly by a capillary tube. As the temperature of the bulb rises, vapor pressure in the bulb increases and is transmitted through the capillary to the cup. The force is exerted against the outside of the bellows, compressing it and moving the attached rod to actuate a switch or valve. A spring is usually incorporated as an adjusting means to provide an accurate setting of control temperature.

DESIGN CONSIDERATIONS

In the design of vapor-pressure systems, several factors must be considered: temperature range to be controlled, required sensitivity and the ambient temperature limits encountered. These requirements must be met by the right combination of bulb and bellows design and the thermal "fill" of the system.

Different combinations of factors are required if the controlled temperature is below, above, or *both* below *and* above the ambient temperature at the bellows.

Controls — bulb temperature lower than bellows. A control designed to operate at zero F, for example, must be charged with a thermal liquid having an active vapor pressure at that point, although the boiling point may be either above or below zero F. Methyl chloride (see Fig. 2) would be a logical filling medium for this application; it has a boiling point just under minus 10F and a vapor pressure of 3 to 4 psig at zero F. When used in refrigeration equipment, it functions satisfactorily, but since it has a vapor pressure of 150 psi at 120F, it would produce excessive pressure when subjected to high temperatures such as during shipment or storage of the unit. To design the assembly to withstand the overpressure would unnecessarily reduce the sensitivity of the control.

This is easily avoided in Clifford units through a calculated limited filling of the system. A volume of volatile liquid is selected so that it will be completely

Figure 3. Clifford vapor pressure bellows assemblies are widely used in refrigerators. They provide positive action for the close temperature control essential to modern refrigeration.

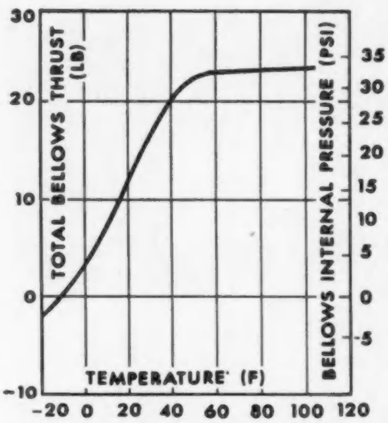


Figure 4. Temperature vs. thrust curve for a 1⅛" bellows with limited fill of methyl chloride. Full vaporization is complete about 50F. Only negligible gaseous expansion occurs above that point.

vaporized at a temperature just above the maximum desired control temperature. Beyond that point, only gaseous expansion takes place. Figure 3 shows the limited fill curve for a typical filling medium used in refrigerator temperature controls. Standard Clifford vapor pressure assemblies already engineered are obtainable for control of temperatures as low as −40F.

Ambient temperature has no significant effect on low temperature controls, because the volatile liquid is wholly contained in the bulb, which is usually quite small and located in the chamber to be controlled.

The pressure throughout the entire thermostatic assembly is always governed by the bulb temperature.

Controls—bulb temperature higher than bellows. For controls designed to operate at temperatures higher than the ambient temperature at the bellows, the assembly is almost completely filled with liquid. The vapor pressure is generated at the hottest point (the bulb) and transmitted to the bellows cup by the hydraulic action of the filling medium. The bulb is designed to trap the vapor within it, so that only *liquid* is forced out of the bulb and into the capillary and bellows cup. Over-temperature protection can be provided by limiting bulb size. Controls of this type are unaffected by ambient temperature. *The vapor pressure in the system is always a function of bulb temperature.*

Universal service. For control of temperatures *both* below *and* above the ambient temperature at the bellows, universal systems can be designed that draw on the principles of operation of both the low and the high temperature types just described. The bellows cup, capillary and bulb assembly is charged with a definite, precisely measured volume of the thermal liquid. When the capillary and bellows cup are *completely filled* with the thermal liquid, there must still be enough liquid left in the bulb to generate the necessary vapor pressure.

When the bellows and capillary temperatures go above the operating temperatures at the bulb, the liquid in the bellows and capillary vaporizes, expands into the bulb and condenses. The bellows cup is thus filled with a superheated gas at the same pressure as the vapor pressure generated by the volatile liquid in the bulb. A transition point is reached when the temperature of the bellows and capillary just equals that of the bulb. As the temperature of the bellows and capillary drops *below* that of the bulb, the liquid in the bulb rapidly vaporizes and condenses in the bellows and capillary until they are completely filled. Bulb design provides for some liquid to remain in the bulb. Further temperature increases bring about an increase in vapor pressure which is transmitted hydraulically through the capillary to the bellows cup.

Under any of the above conditions the temperature at the bulb always controls the operation of the system. The universal type control satisfies requirements that can be filled by neither the low-temperature nor high-temperature vapor-pressure types alone.

Dual Fill - Universal service can be obtained by a "dual fill" system. The unit is filled with controlled amounts of two insoluble liquids. Temperature changes are sensed by one liquid and the resulting vapor pressure changes are transmitted hydraulically through the second liquid to the bellows cup. This type of unit can be designed to have the "knock off" characteristics of the limited-fill unit (see Fig. 3).

"Fail-Safe" Design. If a liquid is chosen with a boiling point *above* the control point, the system operates under vacuum up through the control point. Vacuum should usually be limited to about 15 inches of mercury. Vacuum operation provides a "fail safe" feature in such applications as automobile thermostats. In the event that leakage occurs in the bellows or elsewhere in a closed system, the thermostat locks "open" and coolant continues to flow through the system. When controlling a heating medium, the control locks "closed" to shut off the source of the supply of heat.

Thrust. In vapor pressure assemblies, the thrust of the bellows at any temperature is definitely fixed by the vapor pressure of the filling medium and cannot be changed. Similarly, thrust differential between any two temperatures is fixed by the filling medium. Therefore, in the mechanical design of switch or valve mechanisms, friction should be minimized and maintained at a constant value.

Adjustment is commonly achieved by means of a spring and adjusting screw arrangement. The spring can control the operating temperature, the operating differential and the range over which the control temperature can be adjusted. The adjusting spring mechanism must be interrelated with the bellows cup assembly to achieve the desired operating characteristics.

Barometric compensation. For systems requiring extreme accuracy, it is sometimes desirable to compensate for barometric changes. Such correction is provided simply and accurately by a Clifford differential pressure unit (see Fig. 6). The vapor pressure is transmitted to the outside surface of the large bellows. The other side of the bellows is evacuated. The barometric changes then act on the areas of the smaller bellows, producing a null effect.

Clifford Manufacturing Company will consult with you regarding a thermostatic assembly that will meet your requirements. If you have an immediate problem, send a sketch showing controlling factors of your application and we will recommend a suitable control.

Clifford Manufacturing Company, 139 Grove Street, Waltham 54, Mass., *Division of Standard Thomson Corporation.*

Sales offices in New York, Detroit, Chicago, Los Angeles, Waltham, Mass.

7·5·14

HYDRON METAL BELLOWS — CLIFFORD MANUFACTURING CO. WALTHAM, MASS. DIVISION OF STANDARD THOMSON CORP. — HEAT EXCHANGERS

Figure 5. Temperature regulators for water heating or cooling tanks, steam cookers, acid baths, glue heaters, bottle washers, tempering baths and other heating specialties used Clifford vapor pressure bellows assemblies as actuating elements.

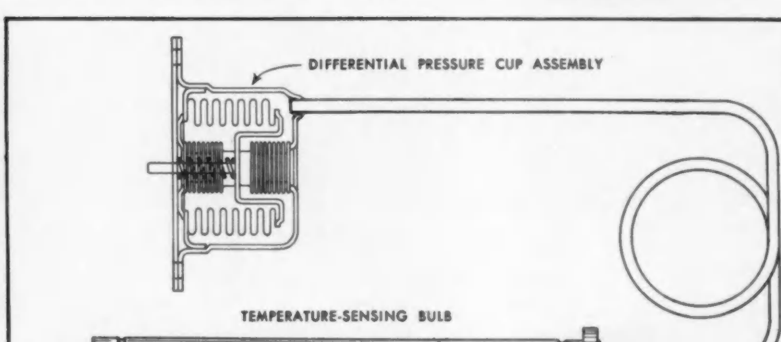


Figure 6. Vapor pressure bellows assembly with automatic barometric compensation.

FULTON SYLPHON

TEMPERATURE REGULATOR HEADQUARTERS,

Customer confidence has made Fulton Sylphon a leading supplier of temperature regulators . . . indeed, headquarters for temperature regulator know-how. Consider this extra advantage to you before buying any regulator.

You are confident of the right regulator for your requirement! Fulton Sylphon offers a complete line of temperature regulators for industrial process control; engine controls; heating, ventilating and air conditioning . . . provides latest engineering advances in efficient, lower-cost temperature control.

You are confident that the very finest engineering service is focused on your temperature control problem. Whether it involves field or plant engineering, your problem receives the prompt, specialized engineering service that only a leading supplier can afford to provide—without cost to you.

You are confident of dependable performance in the field. Fulton Sylphon Temperature Regulators are produced under the most rigid quality control standards. All parts are made by Fulton Sylphon to exacting, time-proved specifications. The diaphragm of each regulator is an all-metal Sylphon Bellows, originated by Fulton Sylphon and universally specified for the most critical military and industrial applications.

You are confident of competent, near-by field service. Fulton Sylphon technically trained representatives in 50 cities throughout the United States assure you of fast, on-call service.

Several types of Fulton Sylphon Temperature Regulators are described on the next page. For full information on these, and other types, use the convenient **coupon**.

Control Principles and Hardware Span a Continent:

IN CHICAGO,
the Production Engineering Show, along with the first Machine Tool Show since 1947, offered vivid proof that control engineering principles already guide the design and application of some metal fabricating processes. Status: the concepts are there but they still must be understood on a broad scale before the industry can surge ahead in their use.

IN LOS ANGELES,
the Instrument Society of America's 10th annual conference and exhibit showed, in its fine technical sessions, a vigorous growth in the use of engineering principles in continuous flow process control. Status: while the remarkable array of hardware still anticipates most industrial needs, the skilled user is already groping for new concepts.

From Sept. 6-16, in two great trade shows spaced across the nation, the control engineer had a unique opportunity to assay the state of his art in terms of real developments, and in its broadest possible context.

Starting on the 6th, he could have prospected in Chicago for feedback control at work in metal cutting by riding out to the Stockyards Amphitheatre for the Machine Tool Show and to the auxiliary Production Engineering Show on Navy Pier. Then, on the 12th he could have flown to Los Angeles where in the Shrine Auditorium he would have been able to take stock of a year's progress in industrial control at the Instrument-Automation Conference and Exhibit. And, while in the area, if he happened to visit a few local aircraft plants, he would have just about run the gamut in control: production, process, and military.

But the control engineer who went to Chicago may not have been rewarded at first glance. Familiar with past ISA and, perhaps, IRE shows, his first instinct probably was to go to Navy Pier to review the gadgets and hardware used to control machine tools. Some marathon scanning of the 200-odd displays on the long pier must have left him slightly confused. Of the many booths, perhaps a dozen featured equipment familiar to the control loop: three or four dynamic motor control arrangements, a few tape-servo director systems for machines, and some splendid uses of solid state devices by a trio of well known electrical control manufacturers. It seemed that the bulk of equipment consisted either of machine shop accessories, or what the trade knows as "automation"—transfer devices and the like. So our control engineer felt like a delighted homing pigeon when he came to roost at the University Exhibit (see September 1955, pp. 129-136, and p. 26 in this issue for a description of this special display) for some chitchat about feedback with one of the bright young graduate students on duty.

Out by the stockyards, however, confusion was replaced by awe. True, all our man could see and hear were huge, forceful machines stamping, grinding, turning, boring. No familiar

TRENDS SPOTTED IN CHICAGO . . .

hiss of controlled air or click of stepping relays could be detected above the din. No revealing glimpse of a black box could be gained in a background of thrusting and whirling massive steel forms. His awe came not from control, but from the monumental performance of apparently *uncontrolled* machines. Control was momentarily forgotten.

But after several fascinating hours of trudging and peering, some vaguely familiar things formed out of the background. Wasn't that a tape-controlled director system over there in the corner of the Jones & Lamson booth? How about that statistical gaging gadget on the Bryant bearing race grinder—wasn't the grinding carriage being controlled by a feedback signal from the gage? And what about those hydraulic servos that appeared on a host of tracer-controlled machines?

The upshot of this awakening was a decision by our control engineer to prolong his stay in Chicago for a thorough combing of the big tool show. For a quick impression of the trends as he saw them, review the pictures on the right of this page. And for a more revealing discussion of the status of feedback in metal fabricating, turn to *Industry's Pulse* on page 51.

On to Los Angeles

Flying to Los Angeles on the crisp Sunday of Sept. 11, our engineer reflected on Chicago. He had seen many sophisticated, and suprisingly, simple and effective examples of the control art in machine production. But why had the exhibitors "buried" these away in a corner? And why did attendants look blank when they were asked about feedback and the mechanics of continuous gaging? He concluded a) that feedback control was still a minor issue in machine tools, and b) that engineers skilled in control were also still in a minority in the industry. Well, on to L.A. At least there he could be sure that control was a) very much a major issue in the exhibit, in fact *the* issue, and b) that engineers skilled in control were becoming a rule in the process field.

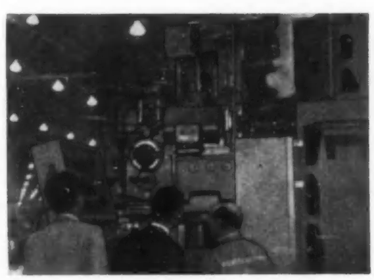
Our peripatetic control engineer was not disappointed. The worst smog in Los Angeles' history could not dampen an enthusiasm built up at Shrine Hall by the technical competence and importance of many papers on his program. Some samples:

- ▶ seven original studies in the dynamic analysis of elementary process control
- ▶ four special sessions, 16 papers, on plant product analysis techniques
- ▶ symposia on data handling, transportation, and nuclear instrumentation
- ▶ daily clinics for engineers on computers and analytical measurements

When he could break away from

SOLID STATE DEVICES for controlling machine tools were impressively displayed at the Production Engineering Show. This Westinghouse panel was augmented by three attractive girl spielers who chimed, in unison, about the merits of "Cypak" components. The components were also nicely made: dip-soldered printed circuitry at an average cost of about 1.5 times the comparable relay circuit. Incidentally, W. F. & John Barnes used "Cypak" in a control panel at the Machine Tool Show.

TRACING AND CONTINUOUS GAGING appear to be fast-growing approaches in machine tool operation. The Pratt & Whitney vertical profile miller (above, left) used Keller tracer controls—the sample workpiece was followed by means of an on-off relay type servo. Most of the tracers, however, used hydraulic follower systems. The Landis Tool Co. automatic crankshaft grinder (above, right) included a simple closed-loop between a pneumatic grinding tolerance gage and the final stage of grinding carriage travel. Similar gaging-with-reset was seen in 13 machines.



DIGITAL TECHNIQUES for machine control are being cautiously tested by the industry—only seven installations were visible in remote corners of the Machine Tool Show. At the Production Engineering display, however, the I-T-E Circuit Breaker Co. (above, left) revealed how its clutches act in a card-programmed control system for a Warner-Swasey lathe. And in the Carboloy Dept. of General Electric Co. booth (above, right) a machinability computer that resolved cutting speed and motor horsepower for a specific job consistently drew interested crowds.

. . . AND SOME OF THE NEW DEVELOPMENTS IN PROCESS CONTROL

the sessions our man discovered that 300 different companies were displaying their wares in booths spread over three floors. As always, the very large booths were occupied by the "old line" process control companies such as Honeywell, Leeds & Northrup, Bailey, and Bristol. However, several West Coast systems firms—relatively new to the field—had sizable booths with rather impressive and offbeat product developments (among these: Consolidated Engineering, Bendix, and Beckman). The large control system venders, however, did not dominate the show. The exhibits broke down roughly into these categories:

Transducers and Measuring	42
* Control Component Hardware	41
Testing Equipment	38
Process Control Systems	34
Services for Control	22
Analytical Instruments	18
Data Processing	18
Servo Type Equipment	12
Computing and Counting	10
Telemetering	8
Unclassified	22

* relays, switches, timers, etc.

New Products in Flurries

Touring the booths with an eye for new things proved almost as taxing to our conrtol engineer as did the Machine Tool Show. Very few completely new concepts in measurement and control stood out alone. Rather, there seemed to be flurries of new products to fill a specific market. For example:

- at least five newly developed electro-hydraulic valve actuators—a flurry in response to the need to match valves to fast electronic controllers
- five major entries in data processing systems—a flurry indicating some fast developmental work by companies eager to make the bandwagon
- several new analytical instruments for in-stream use—a flurry in response to urgent demands by advanced process control engineers
- four new flow computing devices—a flurry to provide linear analog, and even direct digital, output from non-linear "workhorse" flow sensors

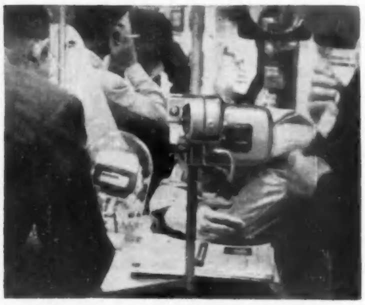
Behind the furries, howeve:, our man did spot many developments whose unique designs portended a promising future. Among these were:

- a new ultrasonic type flowmeter by Fischer & Porter
- Taylor Instruments' first component in a reputed all-electronic line

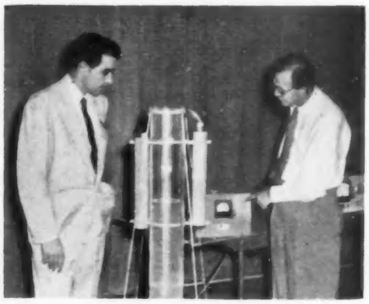
SPOTTING SOME OF THE PROCESS CONTROL DEVELOPMENTS:

FLOW CONTROL proved to be an active developmental area this year at the ISA show. At the right is a sample: Fischer & Porter's new ultrasonic type flowmeter. Its nicely packaged sensing head encloses two transducers that transmit ultrasound upstream and downstream to cancel out sonic velocity. The meter offers no flow restriction and is free of the effects of density, temperature, pressure variations, and occlusions such as gas.

COMPUTING devices serving very special functions broke out on this year's show like a rash. In the close-up on the right the people are peering intently at Foxboro's new flyball integrator—a device which converts a non-linear measurement (mainly flow across an orifice) directly into digits. Librascope, Inc. and Southwestern Industrial Electronic Co. also featured new special purpose analog computing devices for digitizing non-linear flow measurement.



RADIATION measuring techniques also showed a year's progress. At the far right Phil Ohmart, of the Ohmart Corp., puts his redesigned radiation-type level sensor through its paces. By some bold changes in measuring circuitry Phil claims to have brought this basic equipment's price below $1,000—the same being true for density measurement using similar components. This low cost should bring the nuclear approach into an interesting competitive position.

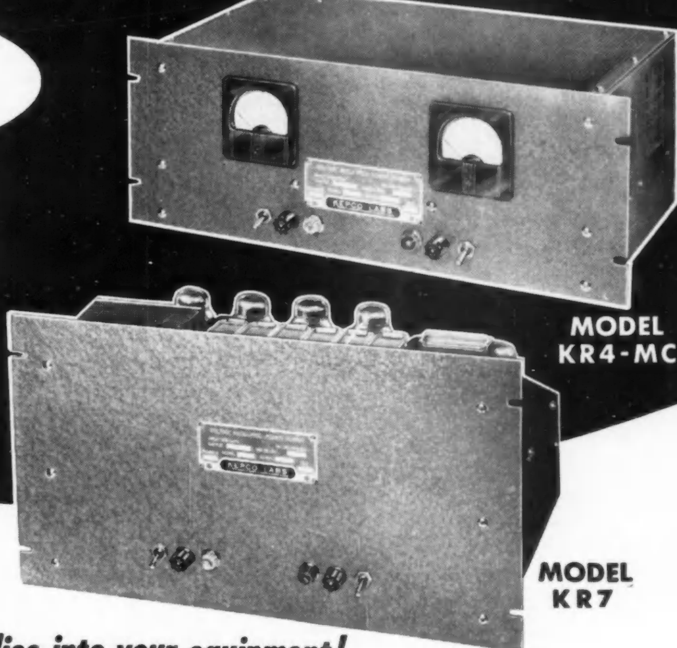


RECORDING instruments are facing some tough competition from direct-digital readout devices—but booths at the show indicated that the recorder makers are doing something about it. For example, West Instrument Corp. has transistorized its strip chart recorder and Honeywell and Bristol have revved up their pen speeds across the chart by neat design. Honeywell's does full scale in ¼ sec by using tach-generator feedback as a pen brake.

KEPCO

KR SERIES

VOLTAGE REGULATED POWER SUPPLIES
for powering electronic equipment



MODEL KR4-MC

MODEL KR7

save time ...*and* money...

Build these compact Power Supplies into your equipment!

- Kepco Voltage Regulated Power Supplies are conservatively rated and are designed for continuous duty at 50°C ambient.
- REGULATION: Specified for each unit is available throughout its output voltage range and is less than 0.2 volts for line fluctuation from 105-125 volts and less than 0.2 volts for load variation from 0 to maximum current.
- RIPPLE: Less than 3 mv. rms.

FEATURES:

- Superior Regulation.
- Ultra-Stable 85A2/OG3 Reference Tube.
- Low Ripple.
- Low Output Impedance.
- Fast Recovery Time, Suitable for Square Wave Pulsed Loading.
- Voltage Range continuously variable without Switching.
- Either Positive or Negative may be Grounded.
- Oil Filled Condensers.
- Wire Harness and Resistor Board Construction.
- Power Requirements 105-125 volts, 50-60 cycles.
- Terminations and locking type voltage control on rear of unit.
- AC, DC Switches, Fuses, and Pilot Lights on Front Panel.
- Color Grey Hammertone.
- Guarantee One Year.

To include 3" Current and Voltage Meters, Add M to Model number (e.g. KR 1-M) and Add $30.00 to the Price.
To include Dust Cover and Handles for Table Mounting, Add C to Model number (e.g. KR1-C) and Add $10.00 to the Price.
To include Meters, Dust Cover and Handles, Add MC to Model number (e.g. KR-1MC) and Add $40.00 to the Price.
PRICES F.O.B. Flushing

600 ma. KR SERIES

Model	Volts	6.3V AC	Rack Mount W	H	D	Price
KR 8	0-150	Each supply	19"	10½"	13"	$330
KR 5	100-200	has two	19"	10½"	13"	$240
KR 6	195-325	10 Amp.	19"	10½"	13"	$240
KR 7	295-450	outputs	19"	10½"	13"	$250

300 ma. KR SERIES

Model	Volts	6.3V AC	Rack Mount W	H	D	Price
KR 12	0-150	Each supply	19"	7"	11"	$270
KR 3	100-200	has two	19"	7"	11"	$180
KR 4	195-325	5 Amp.	19"	7"	11"	$180
KR 10	295-450	outputs	19"	7"	11"	$190

125 ma. KR SERIES

Model	Volts	6.3V AC	Rack Mount W	H	D	Price
KR 11	0-150	Each supply	19"	7"	11"	$180
KR 1	100-200	has one	19"	7"	7½"	$ 90
KR 2	195-325	3 Amp.	19"	7"	7½"	$ 90
KR 9	295-450	output	19"	7"	7½"	$ 97

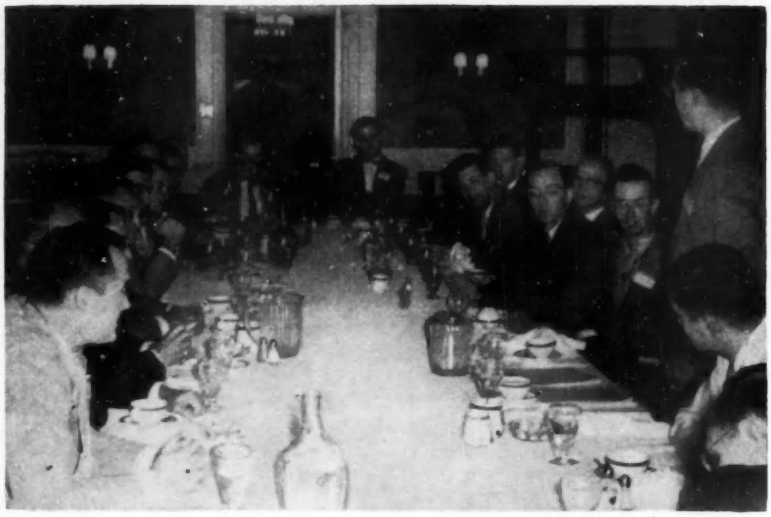
A LINE OF 45 MODELS
Available from Stock – Catalog on Request

RESEARCH • MANUFACTURING
KEPCO Laboratories

KEPCO LABORATORIES
131-38 SANFORD AVENUE • FLUSHING 55, N.Y. • INDEPENDENCE 1-7000

▶ Perkin-Elmer's new vapor fractometer—an industrialized approach to chromatography
▶ Honeywell's and Bristol's new ultra high-speed strip chart recorders

His ardent tour of the booths and sessions didn't prevent our control engineer from taking in the traditional ISA social events, including the annual banquet and lavish rounds of evening conviviality donated by the manufacturers in suites, ballrooms, and bistros. And he was there to applaud outgoing ISA President Warren Brand (Conoflow Corp.) and join in warm wishes for incoming President Robert T. (Bob) Sheen, who heads up Milton Roy Co.



AROUND THE TABLE starting with Bill Vannah, who is standing, and from his right: J. R. Copeland, Antenna Lab, Ohio State U; Donald Moore, Antenna Lab, Ohio State U; Irving J. Stewart, Prod. Eng. Dept., U of Michigan; Irving Lefkowitz, ME Dept., Case Institute; Gordon Roberts, EE Dept., U of Michigan; M. Ramaswamy, Prod. Eng. Dept., U of Michigan; at the far end of the table, John Zisch and By Ledgerwood, Control Engineering; R. A. Kliphardt, Dept. Eng. Drawing, Northwestern U; R. G. Brave, ME, Northwestern U; F. G. Reynolds, ME, Northwestern U; Clifford Crabs, NACA (Case) Cleveland; H. W. Mergler, ME Dept., Case Institute; Gordon Brown, EE Dept., MIT; Norman Gay, ME Dept., Cornell U; Robert Wehe, ME Dept., Cornell U: At Bill Vannah's left: R. W. Lawrie, Bruce B. Barrow, and J. F. Reintjes, all from MIT's Servo Lab. Behind the camera: Lloyd Slater, Control Engineering.

Control Educators Pow-Wow During the Show

The picture above shows 17 representatives from eight universities and some of the editors of CONTROL ENGINEERING gathered 'round a breakfast table for a post-mortem on the universities' exhibits at the recent Production Engineering Show (see September 1955, pp. 129-136, for a technical description of most of these exhibits). Editor Bill Vannah, holding forth at the moment of the photo, called the meeting to find out how their projects went. But it turned out that discussion about the Navy Pier display and its results was brief. All agreed that the booths (see cuts on page 26) were well attended and worth the effort. And that there should be a repeat exhibit each year, if possible.

After this accord came the real session. It seems that grouping control-oriented people from eight different schools in one display area is a provocative thing. The ideas start to flow back and forth across the velvet booth spacers—particularly about how to foster feedback control as an academic subject. At this breakfast the ideas really gushed. Each senior representative got up to describe his school's control education program. Ohio State, for example, is in process of setting up an Automation Institute to sponsor studies in this subject. Case has developed a strong control curriculum in ME because of a certain strong influence named Eckman (Don could not make this meeting). The University of Michigan offers a PhD in Control Engineering, which is served by courses in all departments. And a muscular electrical engineer named Gordon Brown told why control engineering just happens to fall mainly into the Electrical Engineering Department at MIT.

Sitting back and keeping quiet for a change, the editors of CONTROL ENGINEERING got a quick broadside on the problems of setting up and standardizing educational curricula in their field. It was obvious that the obstacles that educators and magazine editors face in this growing technology are quite alike. All agreed that this kind of meeting brought some solidarity in approach and could well become a tradition each year.

Coming down the aisle into the University exhibits, strollers were first greeted by MIT's iron lung (foreground)

For the other things they saw, turn the page.

U. OF MICHIGAN developed this automatic random programmer for psychological testing. But viewers also saw possibilities for quality control and coding system synthesis.

OHIO STATE showed, in this bench-type exhibit, how a servomechanism plus a few logical decision elements can be put to work to optimize, for example, a gas burner.

NORTHWESTERN demonstrated how a dynamometer can be hooked up to a cutting tool to determine optimum machining conditions by measuring forces acting on the tool bit.

CORNELL, in this working display, pinpointed such influences as radial load, bearing friction, lubrication flow, and viscosity in performance of very short journal bearings.

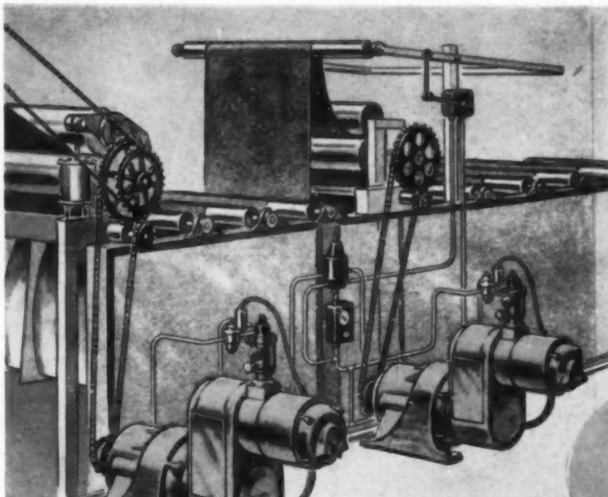
CASE demonstrated an inexpensive numerical machine tool control system. The hardware isn't in this view. But its pipe-smoking spokesman, H. W. Mergler, explains the diagram.

ILLINOIS centered its exhibit on research in high-speed metal cutting and the special instruments used in this work. This A-C Checking Unit is an example of the latter.

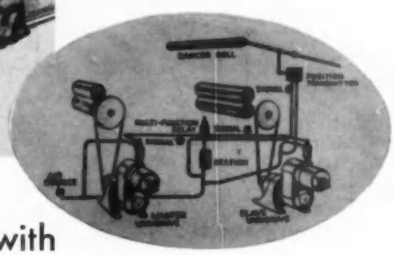
automation in action

EXAMPLE:

SYNCHRONIZATION



Speed of "master" Varidrive is set to desired speed of material. The floating or dancer roll in this process maintains a constant tension. Movement of dancer roll signals "slave" Varidrive to produce proper speed for take-up material.



Accomplishing Automatic Control with VARITROL as a component of the **U. S. VARIDRIVE**

By controlling motor speeds with the Varitrol as a component of the U. S. Varidrive motor, speeds can be automatically changed in response to a signal without human attention for precision-control operations. Above is shown just one of the many ways in which Varitrol automatic control of U. S. Varidrive motors can be used for automatic production control. Varitrol applications obtain efficiency and economy in industrial processes through outstanding savings in processing material, fuel and labor costs.

ADAPTABLE FOR A VARIETY OF DUTIES:

- Constant Pressure
- Proportional flow
- Constant Liquid Level
- Program Control
- Multiple Motor Control
- Filter Control
- Machine Tools
- Constant Cutting Speed
- Speed Control
- Rewind Control
- Constant Flow
- Constant Temperature

Send for Information—**8-Page Full Color Booklet On Automatic Control**

U.S. ELECTRICAL MOTORS Inc. CE-11
P.O. Box 2058, Los Angeles 54, Calif. or Milford Conn.

☐ *Send Varitrol Automation Booklet No. 1882*
☐ *Send U.S. Varidrive Booklet No. 1797*

NAME________________
COMPANY________________
ADDRESS________________
CITY________ ZONE____ STATE________

U. S. VARIDRIVE

WITH VARITROL®

AUTOMATION WITH VARIABLE SPEED

MIT displayed an automatic control system which regulates oxygen flow to an iron lung according to patient pressure pattern measurements.

ILLINOIS TECH showed this operating model of nuclear reactor—an exact replica of the 50,000-watt reactor Armour Research Foundation is now building.

All Around the Business Loop

▶ A multi-purpose research center being built in Des Plaines, Ill., near Chicago, by **Borg-Warner Corp.**, has been billed as one of the most highly diversified in the U. S. Planned as an integral part of Borg-Warner's intensified program of research and development in metallurgy, electronics, acoustics, hydraulics, and other fields, the new center will aim at the future, leaving improvements in existing products to restimulated company divisions. Example: a new kind of sonic oil well drill under study at the **Petro-Mechanics Research Div.** in North Hollywood, Calif.

Units of the center will include a complete machine and model shop, a computation section, an extensive technical library, and an advanced engineering and design department. The latter will concentrate on new products that fit Borg-Warner's present marketing structure. When completed, the laboratory will cover 200,000 sq ft and will replace the company's smaller Central Research Laboratory in Bellwood, Ill.

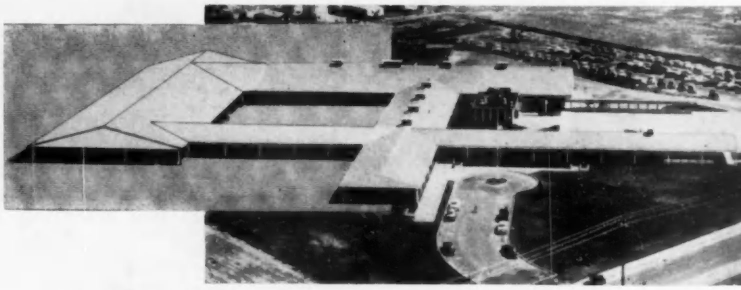
▶ Already in operation in 11 western states is **Quality Control Engineers, Inc.**, of Los Angeles, whose on-premise surveys by trained personnel tell a client, in effect, just how well a manufacturer will come through on a contract. Packaged in its reports, which are pegged to quality control, are such things as the nature of products and processes, degree of accuracy and reliability of performance, ability to meet production schedules, and management know-how. President Harry G. Romig, formerly technical director of quality control for **Hughes Aircraft Co.**, is widely known for his sampling inspection tables, now used as standard equipment in military procurement.

▶ When **Minneapolis-Honeywell** completes a three-story addition to its aeronautical engineering building in Minneapolis – expected time: next spring–the extra 45,000 sq ft will bring about these changes: an expanded analog computer center, already one of the largest of its kind; 30 per cent more elbow room for work in automatic controls and control systems for aircraft and guided missiles, and and increase in personnel.

▶ **Raytheon Mfg. Co.** and **Rensselaer Polytechnic Institute** have set up a series of assignments in Raytheon's laboratories, to be carried out by RPI students who qualify for practical, off-campus work. This cooperative plan, for electrical engineering majors, is similar to arrangements between Raytheon and other universities.

Raytheon, prime contractor for equipment being developed for army ordnance at White Sands Proving Grounds, New Mexico, has set up a laboratory there to conduct tests and evaluations in conjunction with its guided missile test facilities at Point Mugu, Calif. Robert Skidmore goes from Point Mugu to White Sands as work coordinator.

▶ Aeronautical and electronic projects already are under way in the laboratory of **Frank R. Cook Co., Inc.**, of Denver and Colorado Springs. The new company, headed by Cook, formerly director of aeronautical engineering and research planning for **Minneapolis-**



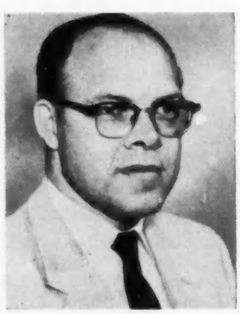
NEW WINGS FOR A SOARING COMPANY. With its work in nuclear magnetic resonance challenging its established klystron tube, Varien Associates decided it needed more room. Result: two new wings (25,000 sq ft) for its Palo Alto, Calif., plant. The wings, shown in white at the left, will be completed early in 1956. They'll increase working space to 63,000 sq ft.

Honeywell, will concentrate on problems in the thermal barrier and all-altitude flight. At present it's at work on transistorized communications equipment and an automatic battery for guided missiles. Civilian applications won't be neglected.

▶ **Gulton Mfg. Corp.** has formed a "scientific group" to carry on research and development in nuclear instruments. Initially, it will look into the use of fissionable materials in instruments for detection, measurement, and control.

▶ Recent acquisitions: **Place Industrial Ceramics Corp.** (film-type resistance element) by **Beckman Instruments, Inc.; Western Inspection, Inc.,** (non-destructive testing of tubular goods in the oil industry) by **Sperry Products, Inc.,** and **The Froham Mfg. Co.** (high-speed shafts, aircraft and precision gears, and gear trains) by **Norden-Ketay.** Norden-Ketay, incidentally, has opened an office in Washington, D. C. to maintain closer contact with its military customers.

▶ Under a new agreement, **D. M. Fraser, Ltd.,** of Toronto, which has represented **Ward Leonard Electric Co.** in Canada, will manufacture the American company's products there. Ward Leonard has acquired a substantial interest in Fraser, a distributor and maker of industrial and marine electrical control equipment.



W. V. Neisius

A. Y. Baker

E. B. Garretson

Important Moves by Key People

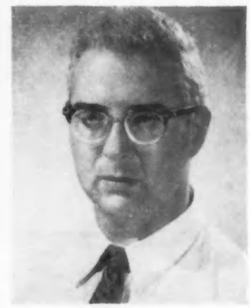
▶ Logistics Research's **W. V. Neisius,** formerly director of applications, and **A. Y. Baker,** formerly Chief Engineer, have been appointed vice-presidents, Neisius' area being applications and sales, and Baker's, development and production.

▶ As new Director of Engineering, **Everett B. Garretson** will direct research and engineering work in General Devices' high-speed multi-contact sampling switches. Garretson goes to General Devices from Garretson Laboratories, Inc., of which he was president. He also has been a consultant and a member of the Plastics Laboratory staff of Princeton University.

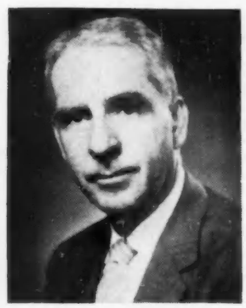
WHAT'S NEW


H. J. Thomizer


Earl Washburn


Joseph Philipson


P. R. Roehm


H. B. Temple


Robert T. Sheen

▶ New division managers of Cook Electric Co. are **Hubert J. Thomizer,** who will head the Magnilastic Div., and **Earl Washburn,** who will be in charge of the Electronic Systems Div. Both men come from Cook Research Laboratories, where Thomizer was project engineer and Washburn, technical director of the Systems Div.

▶ An authority on solid propellants and consultant on chemicals and polymers has been named western representative of Atlantic Research Corp. He is **Joseph Philipson,** formerly with Grand Central Aircraft Co. and Aerojet-General. **Rear Admiral M. F. Schoeffel,** retired, has been elected a director of AR.

▶ **Perry R. Roehm** has been named executive vice-president of Norden-Ketay. Roehm was a research engineer with Carl L. Norden before its integration with Ketay Instrument Corp., later left to become vice-president of Barden Corp., and returned to Norden-Ketay earlier this year.

▶ Another former military man, **Rear Admiral Harry B. Temple,** has been appointed assistant vice-president of Robertshaw-Fulton Controls Co.

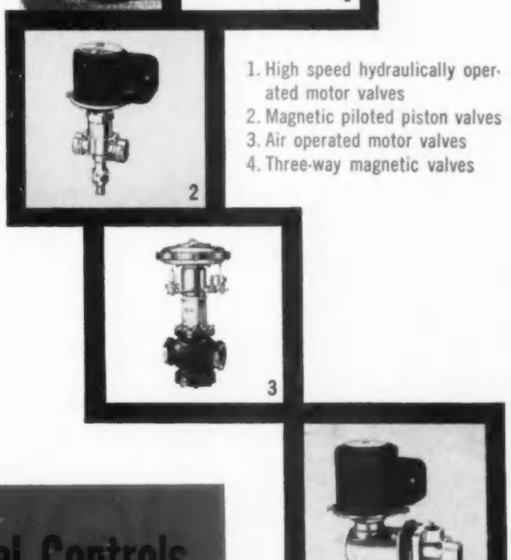
▶ **Robert T. Sheen,** co-founder and president of Milton Roy Co. and Chempump Corp., has been elected president of the Instrument Society of America for the coming year. Sheen for a time was with Monsanto Chemical Co. and W. H. & L. D. Betz Co., serving the latter as consulting engineer. In 1948 he founded Chemical Pump & Equipment Corp. Other posts held in ISA: national vice-president and national secretary.

▶ **Eugene M. Fry** has been appointed instrument development engineer of Glenco Corp., an associate of Gulton Industries, Inc. Fry, most recently Chief Engineer for development and research of Charles Engelhard, Inc., also has been with Bell Telephone Laboratories, Standard Oil, and M. W. Kellogg, Inc.

▶ In line with its reorganization of Equipment Operations. Raytheon Mfg. Co. has named **Nathaniel B. Nichols** manager of commercial equipment engineering. Nichols, formerly manager of the Research Div., has been Research Director of Taylor Instrument Cos., and a member of MIT's Radiation Laboratory and professor of electrical engineering there. Other recent Raytheon appointments: **Burton B. Stuart** to product planning manager, in charge of commercial development of industrial equipment; **Richard G. McLaughlin** to field appli-

Here's a confidence man you can trust . . .

His confidence is in control—the complex, automatically timed control of program and sequence. It makes him complete master of the vast processing operation underway before him. He knows the engineered performance is taking place as scheduled—unmarred by human fallacy or fatigue . . . unaffected by judgments less than perfect, by skills unlearned, by fallible hands, by lapses of attention. He knows that flow and level are on the mark, pressure perfect, temperature pin-pointed, timing true to the split-second operation—all automatically. And the famous red shield of General Controls on the automatic devices which make this miracle of technology possible is his assurance that everything is under control—always, in all ways. He is confident—and you can trust his confidence!



1. High speed hydraulically operated motor valves
2. Magnetic piloted piston valves
3. Air operated motor valves
4. Three-way magnetic valves

G C

General Controls
Automatic Valves

GENERAL CONTROLS

MANUFACTURERS OF AUTOMATIC CONTROLS FOR HOME, INDUSTRY AND THE MILITARY
GENERAL CONTROLS • PERFEX CONTROLS
40 Factory Branch Offices Serving the United States and Canada

• Five Plants: Iron Mountain, Michigan • Glendale, California • Burbank, California • Skokie, Illinois • Guelph, Canada

cations engineer in Los Angeles; **Morris M. Knepp** to application engineer in Chicago; and **Alfred C. Werner** to manager of sales and service in Pittsburgh. **Percy L. Spencer**, a vice-president and general manager of microwave and power tube operations, has been elected a director.

▶ **J. Ernest Smith**, formerly assistant vice-president and director of engineering of Raytheon, has been named Director of Engineering of Datamatic Corp., which is owned jointly by Raytheon and Minneapolis-Honeywell. Also appointed by Datamatic: **Dr. Joseph J. Eachus**, formerly with the Defense Dept. and Purdue University, to Systems Director.

▶ **Hamilton F. Biggar, Jr.**, who has been managing atomic power motor development for Reliance Electric & Engineering Co., now is manager of new product development. New supervisor of the Atomic Power Dept. is **Robert R. Hayes.**

▶ Four engineers have joined the Instrument Div. of Thomas A. Edison, Inc. They are: **R. S. Buritz**, **John L. Rutokowski**, and **Panagiotis D. Georgantas**, project engineers, and **Charles A. Lord**, industrial engineer.

▶ Heading Baird Associates' Transistorized Electronics Dept. as assistant director of research is **Dr. Walter G. Driscoll**, who comes to Baird from the Defense Dept.

▶ Cinema Engineering Div. of Aerovox has appointed **Frank Churchill** manager of the Product Engineering Dept., **Bert Solomon** electronic engineer, and **Dick Earnest** comptroller. Churchill has had experience with Chrysler Corp., Schlumberger Surveying Corp., and the U.S. Navy, and Solomon, with Rayco Co., Photo Research Corp., and Physics Dept. of the University of Miami. Earnest's position is a new one at Cinema.

▶ The Teleregister Corp. has appointed **Bruce Monnacott**, formerly with Control Instrument Co., administrative assistant in systems and procedures. Teleregister is a subsidiary of Ogden Corp.

▶ Two former university instructors have joined the National Bureau of Standards: **Dr. Henry A. Antosiewicz**, who has been named to the numerical analysis section of the Applied Mathematics Div., and **Dr. Kenneth E. McCulloh**, named to the engine fuels section of the Heat & Power Div.

▶ **William E. Keppner** has been named chairman of the board of Radiation, Inc. Keppner, a retired air


From Dogs to Data with Benson-Lehner Data Reduction Equipment.
Scientists at the University of Oregon Medical School are planning to reduce their experimental time to one-fiftieth with their installation of a Benson-Lehner OSCAR Model F, Electroplotter and Electrotyper. Under the directorship of Dr. Archie R. Tunturi, these scientists are making valuable experiments in electronic mapping of brain impulses.
Fifty channels of information are taken from a dog's brain under a wide variety of laboratory conditions. This information is recorded from multi-channel cathode ray oscilloscopes by an aircraft camera. The system produces a large volume of important data which is directly converted into final form by Benson-Lehner data reduction machines. The equipment is helping to establish vital conclusions in a program aimed at gaining an understanding of how the human brain functions.
BL
benson-lehner corporation
11930 Olympic Boulevard, Dept. N2, Los Angeles 64, California
Offices: Los Angeles, Washington, D.C., Ottawa, London, Paris
There are over 400 Benson-Lehner installations throughout the world turning out data in widely diversified fields of science and industry.

force lieutenant general, formerly was executive vice-president of Bell Aircraft Corp.

► **Vincent J. Cushing,** who directed Armour Research Foundation's Cannonball II project, has been named manager of the Propulsion and Structural Research Dept. Cushing, president of the Chicago section of the American Rocket Society, joined Armour in 1950 and has been assistant manager of the department since 1954.

► New appointments in advertising, public relations, and sales include: **Warren C. Wilson,** advertising and PR manager, Servomechanisms, Inc.; **W. H. Dunning,** director of advertising and PR, Electronic Specialty Co.; **John L. Bradley,** assistant manager of advertising and sales promotion, Ampex Corp.; and **George F. Clifford, Jr.,** sales manager, Spinco Div. of Beckman Instruments, Inc.

More News About the Business Loop

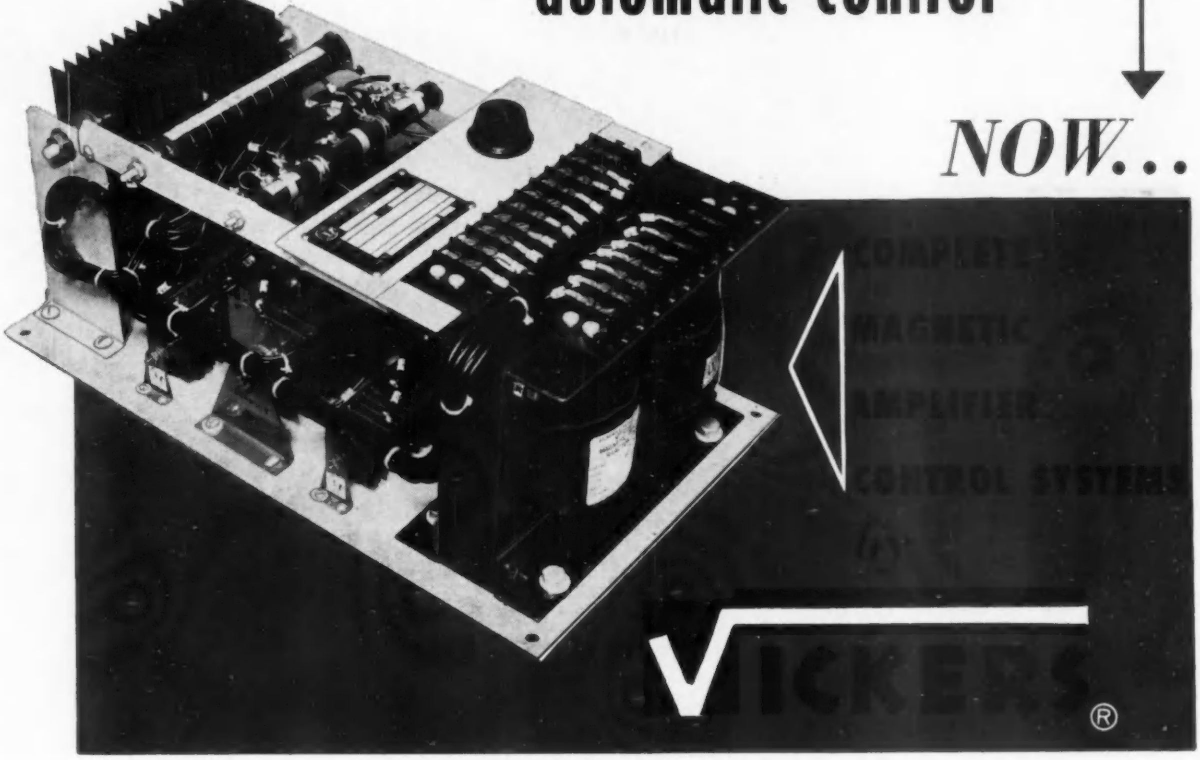
► When **Electro Data Corp.** moved into its new home in Pasadena, Calif., it naturally brought along its "breadboard" computer, which it uses for experiments. This meant transplanting 1,500 vacuum tubes, 3,200 diodes, and 10 miles of wiring. Also brought to the new home, which consolidates four offices in Pasadena, were five Datatron computers, more than a dozen Datareader magnetic tape storage units, and, of course, the company's 300 employees.

► Recent expansions: A sales and distribution office in Toronto for **Ampex American,** the first opened in Canada by **Ampex Corp.'s** wholly owned subsidiary (manager: Ralph E. Endersby); a western regional sales engineering office in Lynwood, Calif., for **Fielden Instrument Div.** of **Robertshaw-Fulton Controls Co.** (supervisor: Charles J. O'Lone); a mid-America region marketing office in Chicago for **Texas Instruments, Inc.** (district manager: Fred W. Young); and a sales office in Tulsa, Okla., for **Hammel-Dahl Co.** (district sales manager: Paul E. Bowles).

► **Librascope's** subsidiary, **Minnesota Electronics Corp.,** has moved from St. Paul to Burbank, Calif. And in Santa Ana, Calif., the parent company has completed a new home for its **Mecca Div.**

for accurate, reliable automatic control

NOW...



FIRST to Produce Commercially-Available Magnetic Amplifiers

Vickers complete Magnetic Amplifier Systems were developed to meet the need for accurate and reliable control in today's rapidly-expanding field of automation.

In addition to custom design systems for particular complex applications, Vickers offers a complete line of standard magnetic amplifiers from milliwatts to 50 kilowatts.

For your automatic control needs, Vickers' full resources, including special engineering skills and years of practical experience, are available to assist you in the solution to your problems.

WRITE TO VICKERS TODAY FOR FURTHER INFORMATION

VICKERS ELECTRIC DIVISION

VICKERS ELECTRIC DIVISION

VICKERS Inc. a unit of Sperry Rand Corporation

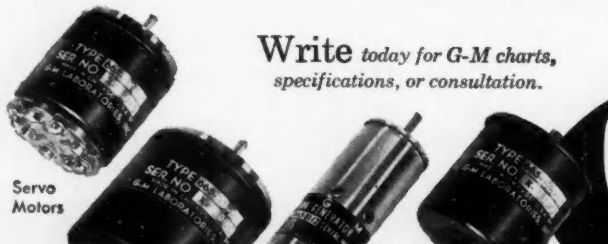
1805 LOCUST STREET • SAINT LOUIS 3, MISSOURI

By specializing in servo motors only—not systems—G-M gives you these advantages...

- A broader line of servo motors in sizes and types to meet a wide range of applications.
- Servo motors available in *all* the standard sizes.
- Standard sizes specially modified to meet specific circuit requirements—available on a quick-service basis.
- Creative engineering in designing special motors with special characteristics.
- Faster production—better service.

When reliability under extreme conditions is essential—specify G-M Servo Motors! G-M has long specialized in supplying precision servo motors to the Military Avionic Industry, especially designed to meet military specifications for humidity, salt spray, temperature, vibration and altitude. Whatever your needs, let G-M build a servo motor with the *right* characteristics to perform to your specifications.

Write *today for G-M charts, specifications, or consultation.*



Servo Motors

Motor Generators

Synchronous-Hysteresis Motors

G-M

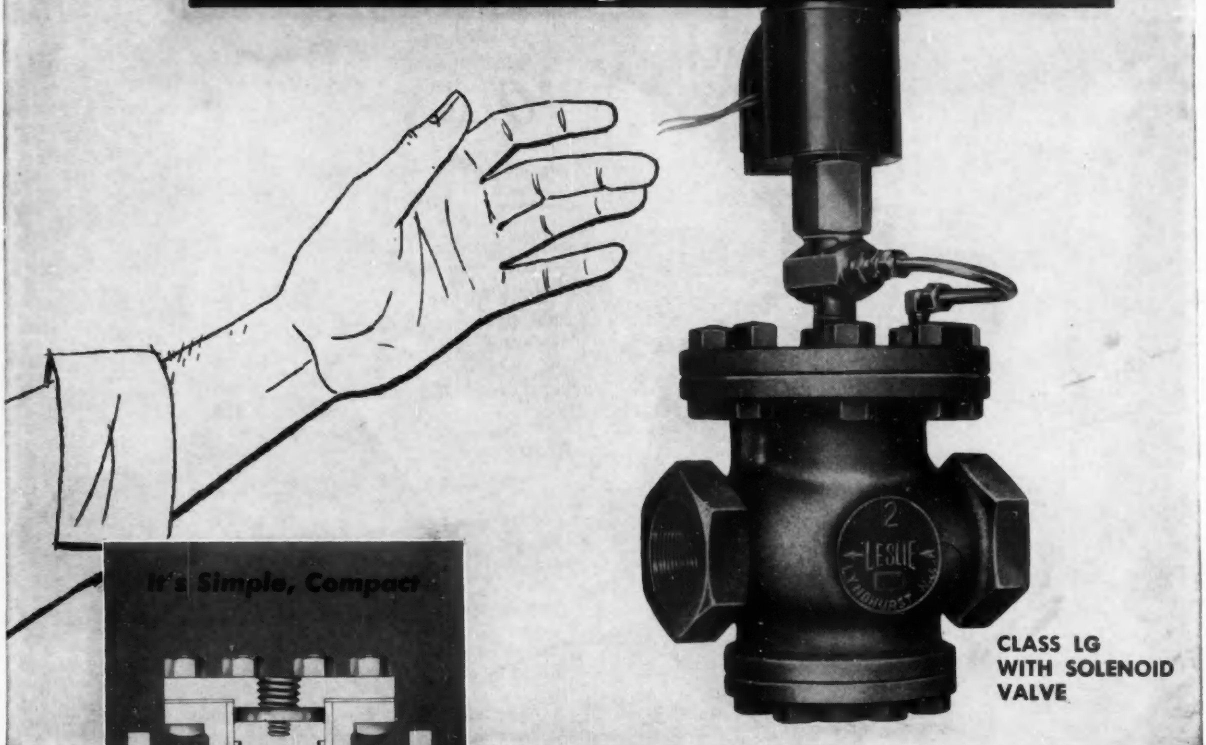
G-M Servo Motors

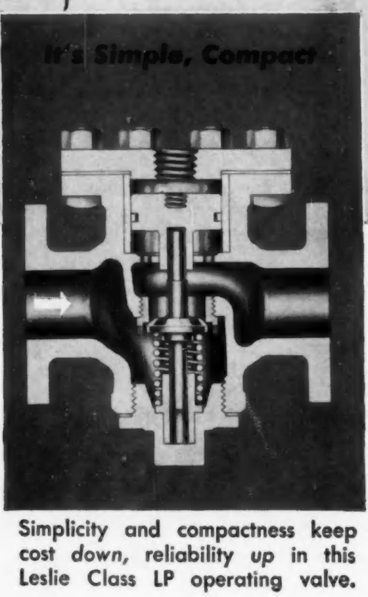
manufactured by the Components Division of

G-M LABORATORIES INC.

4340 N. Knox Avenue • Chicago 41

This operating valve is *always* within *reach*





Simplicity and compactness keep cost *down*, reliability *up* in this Leslie Class LP operating valve.

Make a demand — the valve obeys. It's like having a third hand and a long arm as the control for this shut-off valve is *always* within *reach*.

You can get Leslie shut-off valves equipped with an electric solenoid valve (Class LG) or you can operate them remotely with an air or hydraulic relay valve. Valve opens and closes on demand of a manual or automatic signalling device (pressure switch, thermostat, etc.)

Designed for off-on service, there are units with body ratings to 1,000 psi and temperatures to 750°F. The valves give fast, tight shutoff of steam, air and non-corrosive fluids.

Ask your Leslie engineer to help you select the operating valve that's engineered to meet your service requirements. You'll find him listed under "Valves" or "Regulators" in your classified telephone directory.

Bulletin 5309 describes operating valves. Send for it today.

TRADE LESLIE MARK

REGULATORS AND CONTROLLERS

LESLIE CO., 211 GRANT AVENUE, LYNDHURST, NEW JERSEY

131

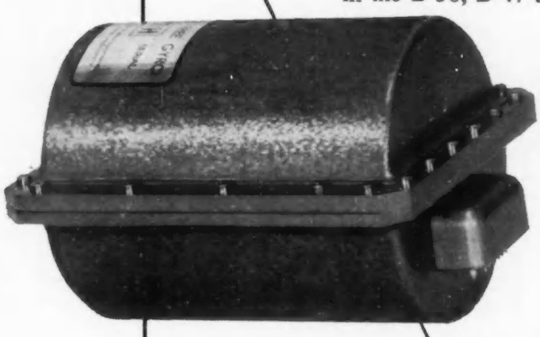
CONTROLLED QUALITY MEANS QUALITY CONTROLS

THE HEART OF THE HOMING SYSTEM

Doelcam

Master-precision Gyroscopes

DOELCAM Master-precision Gyroscopes and Gyro Stable Platforms are standard equipment in many of today's missile and aircraft stabilization and guidance systems. Shown here are three standard models. Specialized versions of these models or completely new designs can be produced in quantity to suit your requirements *exactly*. Avail yourself of the same engineering know-how that has successfully designed gyros for the LARK, METEOR, TALOS, RASCAL, BOMARC and LACROSSE Missiles and the same production team that has made DOELCAM the largest single producer of gyros for the bombing and navigational computer used in the B-36, B-47 and B-52. ***We invite your inquiry.***



Cageable Free Gyroscopes, Type CFG-P (Potentiometer Pickoff) and **Type CFG-S** (Synchro Pickoff) for guided missile instrumentation and control systems. These gyros measure angular deflection about either one or both gimbal axes. The rugged simplicity of the caging mechanism and the rail-type mounting enable these gyros to withstand severe shock and vibration. Weight — 5⅛ lbs. Size — 5 19/32" long x 4⅜" diameter (exclusive of mounting flange). Drift—less than ¼° per minute. Remote caging and uncaging. ***Write for Bulletin CFG34***

Rate Measuring Gyroscopes, Type K for guided missile control and homing systems and flight evaluation of military aircraft. These models measure absolute angular rates where high accuracy and superior dynamic response are essential. Linear output signal proportional to input rate within 0.25% of full scale. Withstand 100G shock in any plane and 15G vibration up to 2000 cps. Weight—3⅝ lbs. Size—5¾" long x 3.20" diameter. ***Write for Bulletin KG34***

Rate Measuring Gyroscopes, Type JR for tactical weapon systems requiring less than one minute warmup. Incorporate damping compensator for constant damping ratio without heater. Linear output signal proportional to input rate within 0.25%. Withstand 50G shock, 15G vibration up to 2000 cps. Angular Momentum — 10^6 gm.-cm.^{2}/sec. Size 3⅜" long x 2.0" diameter. ***Write for Bulletin JG34***

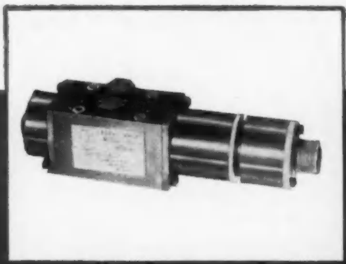
Doelcam

A DIVISION OF MINNEAPOLIS-HONEYWELL H HONEYWELL SOLDIERS FIELD ROAD BOSTON 35, MASS.

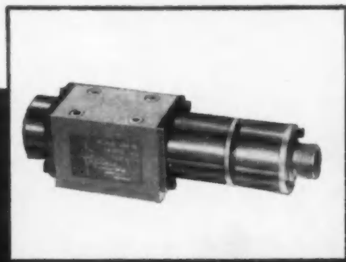
Instruments for Measurement and Control

Synchros • Gyros • Amplifiers • Microsyns • Servo Motors

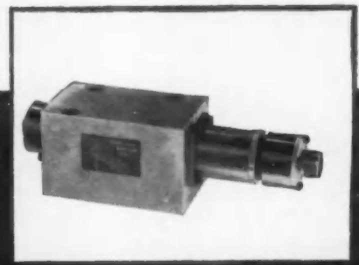

This
is just 1/2 the story...
the new CORE MAGNET MECHANISM
by ROLLER-SMITH
master instrument makers
... outperforms conventional mechanisms of much greater weight in a wide variety of applications ... yet it's rugged and "tops" in dependability.
Combining improved efficiency and performance with miniaturization, Roller-Smith's new Core Magnet Mechanism is an outstanding achievement ... a precision, self-shielding movement that can be counted upon to increase the prestige of your product through consistently excellent operation.
But furnishing this fine Core Magnet Mechanism is only half the Roller-Smith story!
Just as important to you is our ability to furnish the designing skill necessary to incorporate it into your own equipment. The Roller-Smith engineering staff, headed by world-renowned experts and backed by the finest in research and development facilities, will be glad to assist you in arriving at the most practical solution.
ROLLER-SMITH
Instrument Division
CORPORATION
1825 WEST MARKET STREET
BETHLEHEM, PENNSYLVANIA
Precision Products Since 1908



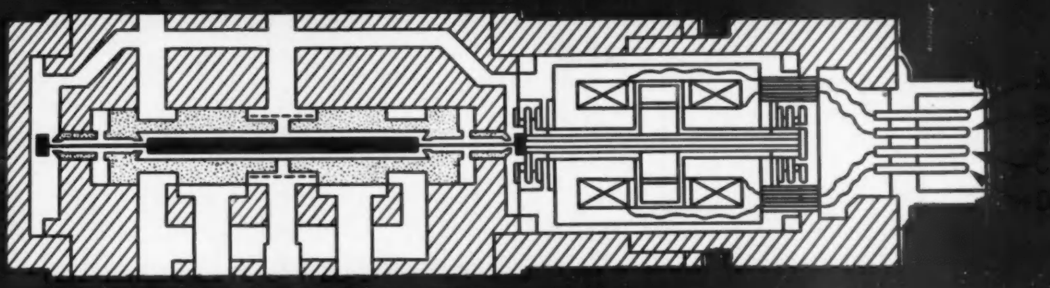
MODEL 120
SERVO VALVE



MODEL 140
SERVO VALVE



MODEL 160
SERVO VALVE



PEGASUS Servo Valves for industrial applications

Pegasus offers industry a line of high performance, electro-hydraulic servo valves designed specifically for industrial applications. They are compact, rugged and reliable, engineered throughout for heavy duty industrial service.

Shown above is a typical servo valve schematic, featuring a balanced, flapper boost stage for maximum reliability, frequency response, and pressure and temperature stability.

These valves are actuated by the Pegasus Model 109 Force Motor, which is hermetically sealed, and transmits motion through balanced bellows. The force motor is available for either vacuum tube or magnetic amplifier application.

Typical industrial applications are: 360 degree contour tracing machines, torquing and load control fixtures, damper testers, chemical valve and variable delivery pump actuators, and wherever difficult problems exist in the control of position, velocity, and load.

SPECIFICATIONS

MODEL 120

Operating Pressure.......200 to 3000
Maximum Flow Rate (1000 psi)..5 gpm
Port Size........................¼"
Internal Leakage (1000 psi) .5 in. ³/sec.
Input Current..............± 40 ma.
Time Constant..................1 ms.
Dimensions..............2" x 2" x 6"

MODEL 140

Operating Pressure......200 to 3000
Maximum Flow Rate (1000 psi).10 gpm
Port Size........................⅜"
Internal Leakage (1000 psi) .8 in. ³/sec.
Input Current..............± 40 ma.
Time Constant..............1.75 ms.
Dimensions...........2" x 2½" x 6"

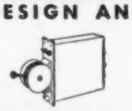
MODEL 160

Operating Pressure.......200 to 1000
Maximum Flow Rate (1000 psi).20 gpm
Port Size........................⅝"
Internal Leakage (1000 psi) 1 in. ³/sec.
Input Current..............± 40 ma.
Time Constant................2.5 ms.
Dimensions..............3" x 3" x 9"

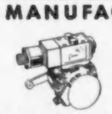
• *More detailed specifications on request.*

PEGASUS LABORATORIES, INC. 3690 Eleven Mile Rd., Berkley, Mich.

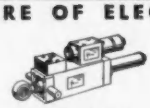
DESIGN AND MANUFACTURE OF ELECTRO-HYDRAULIC SERVOMECHANISMS



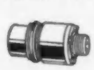
Model 117-C
Transmitter Amplifier



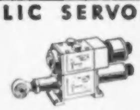
Model 122-120-B
Rotary Actuator



Model 124-140
Linear Actuator



Model 109-F
Force Motor



Model 123-120-B
Linear Actuator

Model 108-D
Servo Amplifier

CHECK ALL B SUPPLIES

YOU WILL CHOOSE

SORENSEN B-NOBATRONS*

PERFORMANCE • DEPENDABILITY • PRICE

SORENSEN B-NOBATRONS (B Power Supplies) were designed specifically to provide an economical answer for a very wide range of technical requirements.

Look them over. Five catalog models, available from stock, give you choice of outputs from 0-325, 0-500, 0-600, and 0-1000 VDC, accurately regulated. High grade engineering, high grade materials, and Sorensen's unequaled know-how in designing and manufacturing regulated power equipment combine to assure you top performance, dependability, and fair price.

**Reg. U.S. Pat. Off.*

DC POWER SUPPLY SPECIFICATIONS

Model	325BB	560BB	500BB	600B	1000BB
AC input range (50-60 cps, 1Ø)	105-125	105-125	105-125	105-125	105-125
Output range (VDC)	0-325	0-500	0-500	0-600	200-1000
Output current (Ma)	0-125	0-200	0-300	0-500	0-500
Regulation accuracy	±0.5%	±0.5%	±0.5%	±0.25%	±0.5%
Ripple (MV-RMS)	5 max.	5 max.	5 max.	3 max.	20 max.
Bias supply (VDC at 0-5Ma)	0-150	0-150	0-150	0-150	—
Internal impedance (max.)	2 ohms	2 ohms	2 ohms	2 ohms	2 ohms
AC voltage (C.T., unreg.)	6.3 at 10 amp.	6.3 at 10 amp.	6.3 at 10 amp.	6.3 at 15 amp.	—
Max. bias circuit impedance	25000 ohms	25000 ohms	25000 ohms	50000 ohms	

Your inquiries for further information will receive prompt attention. Contact your local Sorensen representative, or write to General Sales Department, Sorensen & Co., Inc., 375 Fairfield Ave., Stamford, Conn.

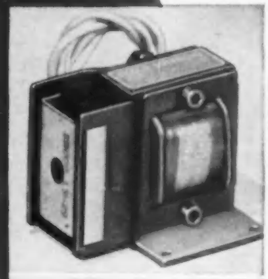
CONTROLLED POWER FOR RESEARCH AND INDUSTRY

SORENSEN

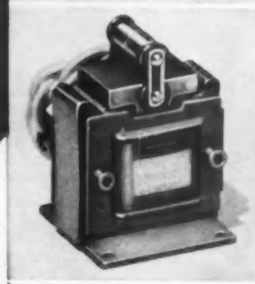
Decco INDUSTRIAL SOLENOIDS

THE *Dependable* ANSWER TO YOUR SOLENOID PROBLEMS

- COMPACTLY DESIGNED—for powerful performance.
- SHOCK-MOUNTED—Reduces self-destruction—greatest cause of solenoid failure.
- HIGH MOISTURE RESISTANCE—Thoroughly impregnated with insulating baking varnish.
- ALTERNATING CURRENT TYPES—Welded base construction for horizontal mounting. Welded or shock-mounted base for vertical mounting. Available in standard voltages, push or pull types, J. I. C. specifications.
- DECCO D.C. SOLENOIDS—are NOT MODIFIED AC SOLENOIDS. They deliver a tremendous force in a small space—ideal for mobile equipment.
- WAFER-TYPE SOLENOIDS—Dependable, small, short stroke, low amperage, push or pull solenoids for small mechanisms and light valving.
- SPECIAL SOLENOIDS ENGINEERED TO YOUR PROBLEMS.

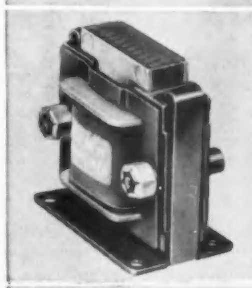


HORIZONTAL PUSH-TYPE—WELDED BASE



VERTICAL PULL TYPE—SHOCK-MOUNTED

VERTICAL PUSH TYPE—WELDED BASE



A C WAFER SOLENOID

D C INDUSTRIAL SOLENOID

FOR COMPLETE INFORMATION ON ALL DECCO INDUSTRIAL SOLENOIDS • WRITE:

Decco — THE HEART OF DEPENDABLE AUTOMATION EQUIPMENT

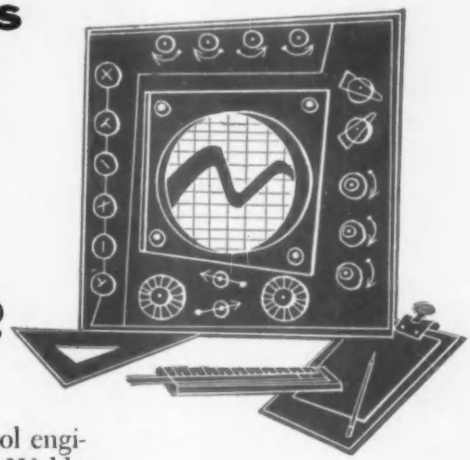
DETROIT COIL COMPANY

2435 HILTON ROAD, FERNDALE 20, MICHIGAN


SM-64
NAVAHO

INDUSTRY'S PULSE

How Much Control Will Metalworkers Use?



Two recent surveys point to a bright future for control engineering techniques in the vast metalworking industry: Waldo Kliever's analysis of automatic machining, which concludes in this issue of CONTROL ENGINEERING, and *American Machinist's* Special Report Number 402 on industry planning in 1956.

Kliever's survey reveals the potential for control hardware in machine tools. It examines today's groping for measurement and feedback principles in guiding, positioning, and programming, and suggests many control techniques that may find practical use tomorrow.

A great potential for control—and for dollars

American Machinist, a McGraw-Hill magazine, views the broad potential. Its survey of 1,574 metalworking companies indicates plans to spend almost $2 billion for new machine tools in the next 18 months. It pinpoints those who will do the most spending and the importance to the buyer of the automation concept.

The recent Machine Tool Show presented a rare opportunity to measure actual against potential (a new story on the show is on page 20). Six years of intense development culminated in a display of over 500 new machines. By and large, these are the machines that *American Machinist* predicts will be bought. Two vital questions are: how many of the techniques discussed by Waldo Kliever are now found in commercial design, and how sought after are the models using these techniques?

Consider first the "muscles" for control—what Kliever calls modulating actuators—which drive the carriage holding the workpiece or tool an amount proportional to a control signal. The bulk of these positioning servos were seen on 18 companies' new contour tracing machines. Of these, 15 were hydraulic and only three electric. About one-half of the tracing actuators were developed by the tool maker. The remainder were subsystems supplied by an outside vendor.

Control specialty firms do some supplying

On 13 machines, positioning servos also tied in with continuous dimensional gaging and automatic reset. The dimension sensors, mainly pneumatic, applied to grinders, gear formers, and a few lathes. Some of these systems were simple "slow-down" and limit control. But several automatically indexed the tool on a statistical distribution basis.

Numerical programming—the most talked about machine control technique—was harder to find at the show. Of the

mere seven tape-controlled units spotted, three were developed by the machine tool manufacturer and the others supplied by control equipment firms.

Other control trends were more obvious. One, variable speed drives in place of, or in addition to, gear changing, was a heavy favorite. Where gear changing was required, electric, pneumatic, or hydraulic clutches were usually picked for the job. Another trend noted: dialing in speeds plus sequence of operation.

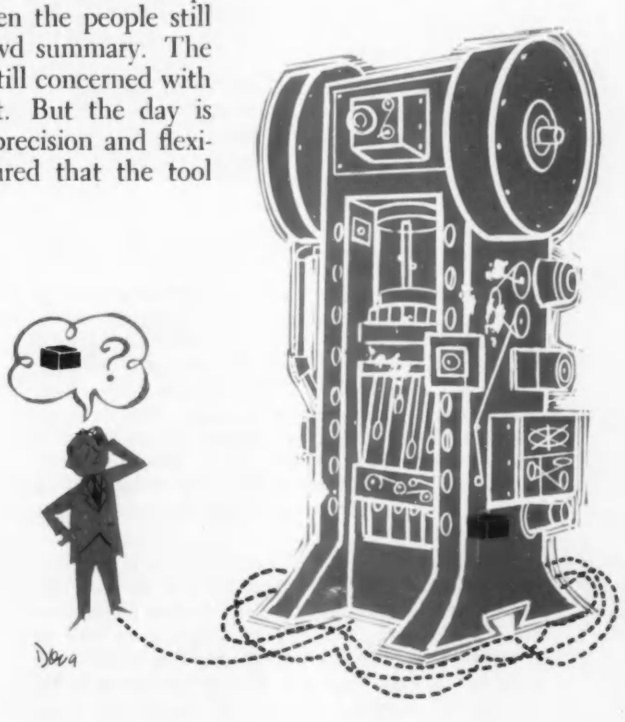
The big interest in automation—automatic transfer, loading, and assembly—stressed in the *American Machinist* survey, was borne out strongly at the show. More than 50 machines featured integrated loading and unloading devices. And, for the first time, units of three tool makers were packaged into an automatic grinding line for ball bearings.

In terms of actual buyer interest, too, automation took the lead over feedback. Interest concerted on the machine that cut more metal—and on the transfer and loading devices that helped to make this possible. Most booth attendants admitted that few dug in to find out how gaging and feedback also contributed to machine throughput.

The manufacturers were somewhat responsible for the subordinate role of feedback control. Most of the tape-programmed developments were relegated to corners of the booths—possibly because the majority were not ready for sale. And with no placards to point them out, control components were buried away or dwarfed by the immensity of the machines themselves.

When queried about the absence of spotlight and fanfare for its feedback control developments, one manufacturer said, "Sure we're spending money and time on fine control developments. But why try to sell microscopes when the people still want a magnifying glass?" This was a shrewd summary. The show proved that the machine tool buyer is still concerned with gross results—cutting speed and throughput. But the day is coming fast when the selling point will be precision and flexibility—a special forte of control. Rest assured that the tool makers will have their "microscopes" ready.

Where oh where is the black box?



Control ENGINEERING
NOVEMBER 1955

Consider the Human

In our opinion the control systems designer does nothing but good when he increases a plant's productivity or decreases its manpower requirements with automatic control. The benefits to the entire society are apparent. But just as apparent should be the benefits to the individual who tightened nuts all day until he was replaced by a machine. We believe that the new generation of maintenance men will use its human capabilities much more constructively than the men who act as a substitute for a controller, linkage, or actuator; that "an industry of designers and maintenance men" is preferable to one composed of human robots.

But intentions are not enough. The control systems engineer has avoided the obvious problems of the suddenly displaced. And, just as great, the positive aspects of his social responsibilities.

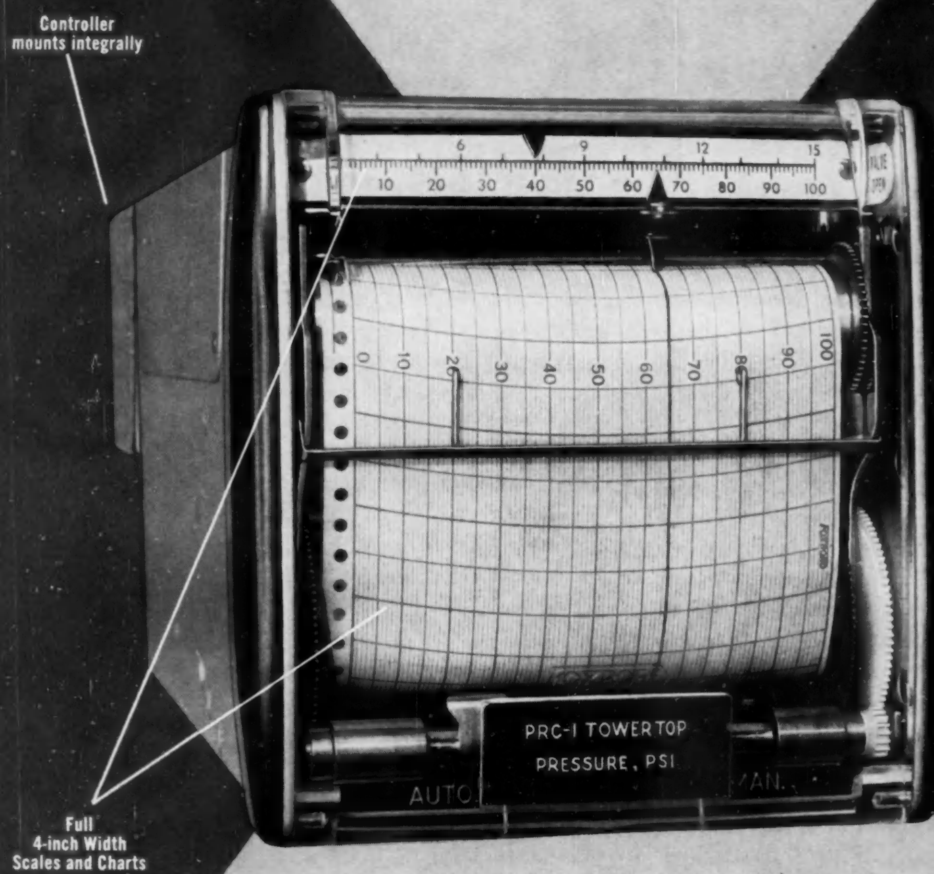
The human problems of automatic control vary with circumstance. But the role the control engineer could play in solving these problems is clear. Having helped to create a labor surplus, or obviate a skill, he has a special understanding that can be used in the planning for relocation and reeducation. Further, because of his special skills, his social responsibility can carry beyond his immediate community. A recent project of the Society for the Social Responsibility of Science points his way. Under the direction of Professor Victor Paschkis of Columbia University's Heat and Mass Flow Analyzer Laboratory, members of the society are organizing a research group to develop specialized agricultural implements for backward areas. Here, organizational skill, engineering know-how, and technical prestige are combining in a humanitarian project completely unrelated to the occupations of the sponsors.

Because special skills and power do carry proportional social responsibility, control systems engineers are in an excellent position to display this consciousness today.

THE EDITORS

NOW...

compactness with nothing sacrificed!



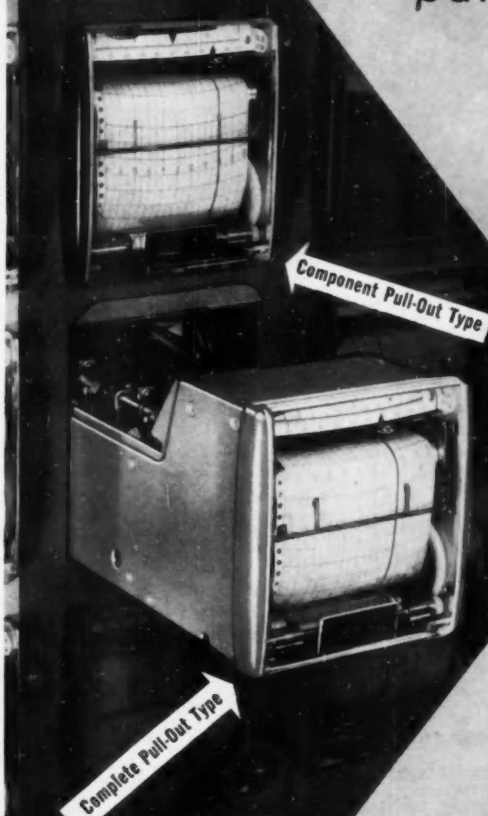
Models to Meet All Your Specifications

In all the following CONSOTROL instruments, recorder and indicator units can be easily converted in field.

- Recording Control Station with automatic/manual transfer
- Recording Control Station with manual loading only
- Recorder — single or two pen
- Indicating Control Station with automatic/manual transfer
- Indicating Control Station with manual loading only
- Indicator — single or two pointer

CONSOTROL

small-case panel instruments



Here's the "tops" in centralized recording and control efficiency! CONSOTROL* Instruments require the minimum of valuable panel space, yet provide unsurpassed operator convenience, visual accuracy, and ease of maintenance . . . maintain the highest standards of precision and dependability. For example: the simple CONSOTROL method of switching from automatic to manual control requires no memory or extra operations . . . never "bumps" the process. All CONSOTROL charts and scales are full 4-inch width for greatest visibility . . . highest accuracy. When it comes to servicing, there's plenty of "finger room" . . . all parts are uncrowded and easily removable. And just compare inking requirements with other designs. CONSOTROL needs ink filling only once or twice a year! These are only a few of CONSOTROL's advanced design features — available in both fixed-mounting and full pull-out type instruments. Get the complete story. Write for Bulletin 13-18. The Foxboro Company, 3611 Norfolk Street, Foxboro, Mass., U.S.A.

*Reg. U.S. Pat. Off.

FOXBORO

REG. U. S. PAT. OFF.

Consotrol Process Control

FACTORIES IN THE UNITED STATES, CANADA, AND ENGLAND

A Practical Guide to Plant Controllability

THE GIST: Plant controllability is a plant's potential for high-quality control. One figure will not describe this potential. Rather, it is composed of several elements such as the plant process characteristics, the available controller actions and the type of plant disturbances.

This article analyzes the variables that affect plant controllability, clarifies some commonly held thoughts on control and plant behavior, and comes up with four practical rules:

1. Shortening the *dead time* in the plant decreases the value of the *deviation* ratio (where low d.r. values indicate control's ability to reduce a disturbance) at low frequencies.
2. Shortening the *dead time* in the plant increases the attainable rise in resonance frequency due to *rate action* in the controller.
3. If with *proportional and reset action* the resonance frequency remains much lower than one half of the Ziegler and Nichols *ultimate frequency,* then the addition of *rate action* may increase the resonance frequency well above this *ultimate frequency.*
4. *Rate action* is most effective if two major time constants and one or more much smaller ones represent the plant transfer function.

Besides the reasoning and examples which lead to these rules, the article also contains an insert by A. Russell Aikman of Schlumberger Instrument Company, which offers some specific examples of plants with the three transfer functions described by Author Janssen.

J. M. L. JANSSEN,
Royal Dutch/Shell Laboratory, Delft, Holland

Plant controllability—a plant's ability to be controlled—must not be confused with the way a plant actually *is* controlled. That is, *controllability* is not the same as *control* quality. However, it is obvious that controllability determines the *potential* control quality.

With this subtle difference in mind we now ask: can potential and actual control quality be measured with the same yardstick?

Consider the tolerance in product as a possible yardstick. Plant conditions should hold within prescribed values in order to adhere to product specifications. Let us assume that only the magnitude of plant deviations, and not their time pattern, influences the product. Then the width of the zone of deviations serves as a natural yardstick for measuring control quality. However, measuring *potential*

DEVIATION RATIO DEFINED . .
. . . AND APPLIED

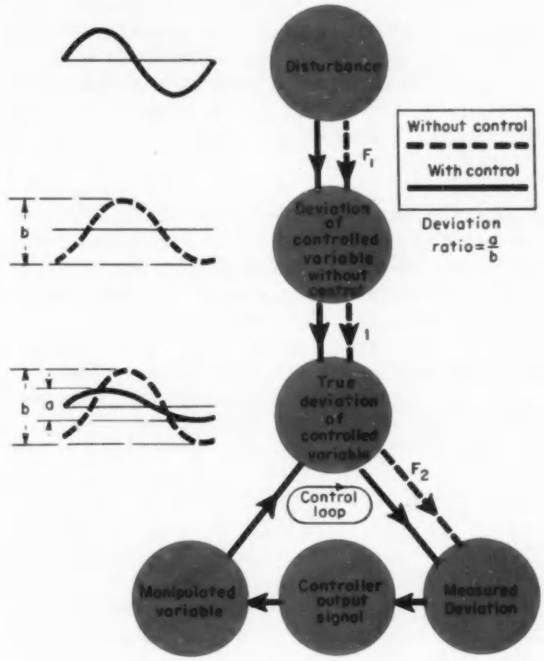


FIG. 1. Plant control system schematic shows paths of signals with control (solid lines) and without control (dashed lines). When a sinusoidal signal disturbs the system without control the output signal, b, results. However, when the loop is closed, the same disturbance produces an attenuated output, a. The extent to which automatic control improves response is measured by the deviation ratio, where d.r. equals a/b.

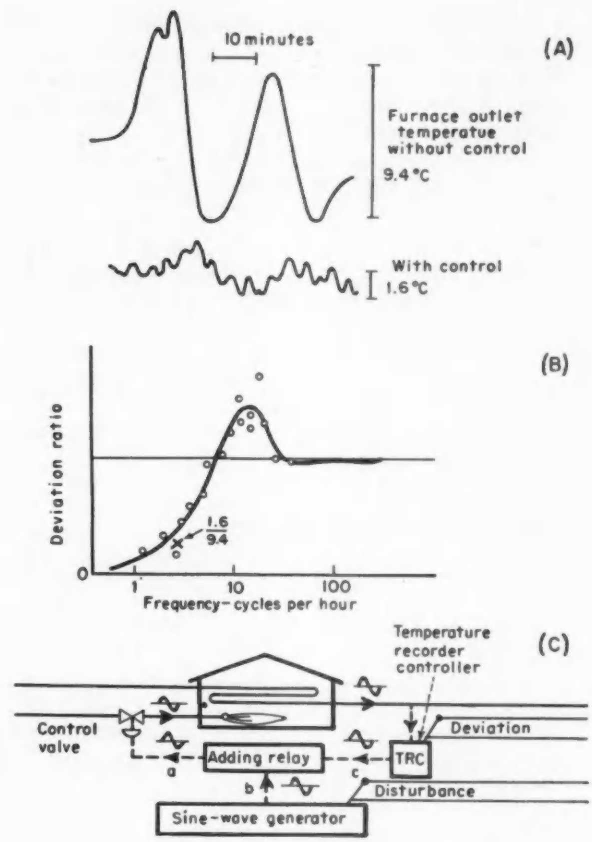


FIG. 2. The curves in (A) indicate the extent to which automatic control diminishes the output signals of a furnace control system. In (B), the deviation ratio for this same system is plotted. The peak value of the deviation ratio occurs at the resonance frequency. The block diagram in (C) shows the measuring set-up for taking the information plotted in the deviation-ratio curve.

GLOSSARY OF TERMS

a = amplitude of sinusoidal deviation with control
b = amplitude of sinusoidal deviation without control
c = amplitude of sinusoidal variation in controller output
f = frequency
f_u = ultimate frequency; at this frequency the plant phase shift is 180 deg
$d.r.$ = deviation ratio
F_1 = transfer function from disturbance to controlled condition
F_2 = transfer function from true deviation to measured deviation
A,B,C = transfer functions of plants A, B, and C, respectively
k = proportional gain of controller
k_u = ultimate proportional gain of controller. It corresponds to the limit of stability if the controller has proportional action only
K = proportionality factor in the relationship between the low-frequency gain of the open-loop and the frequency
P_r = resonance period; this is the period of the sine wave at which the deviation ratio has its peak value
P_u = ultimate period; this is the period of the sine wave at which the phase shift is 180 deg
t = time
α = parameter determining the additional low-frequency gain that is associated with inverse-derivative action
β = factor relating the peak value of the deviation to the plant attenuation at the resonance frequency and the magnitude of the disturbance, for a step disturbance
T = time constant
τ_1 = reset time
ω = angular frequency

control quality with this yardstick becomes much more involved. In fact, the many potential disturbances, potential control equipment, and potential control settings completely defeat the search for a simple controllability yardstick.

Although we have established that controllability cannot be measured, it can be *described* for a variety of settings. The variables that compose this description include:

- DISTURBANCES—three basic types will be considered: step-change, constant rate (ramp), and sinusoidal disturbances
- CONTROL EQUIPMENT—controller actions covered include proportional, reset, rate, and "inverse derivative" action
- PLANT—in particular we will consider the effect of *dead time* on plant response

THE DEVIATION RATIO

Before considering these variables let us examine a concept that evaluates the effect of these variables. This is the *deviation ratio*[1]—the factor by which the effect of a sinusoidal disturbance is reduced by automatic control. In a specific application *deviation ratio* quantitatively compares deviations when the controller is inoperative against deviations caused by the same disturbance when the controller is operating properly (see Figure 1). Since the input disturbance is sinusoidal and the plant is assumed linear, the outputs—with and without control—are also sinusoidal. Therefore, *deviation ratio* describes the results of control in terms of frequency response.

Consider the basic formula for *deviation ratio:*

$$\text{Deviation Ratio} = \frac{\text{Deviation with Control}}{\text{Deviation without Control}}$$

The *deviation ratio* is independent of all factors by which both its numerator and denominator are multiplied. For instance, time lags of the measuring unit cause rapid fluctuations in the measured variable to appear smaller than actual size. This attenuation factor has equal effect on deviation measurements with and without control. Therefore, it is immaterial whether the *deviation ratio* results from true deviation or measured deviation signals (Figure 1, F_2).

Similarly, the point of incidence of disturbance does not matter. Since the direct transfer, F_1, from the point of incidence to the controlled variable is the same with control as without, the *deviation ratio* is independent of any change in this transfer function. Dividing the numerator and the denominator of the *deviation ratio* by F_1 transforms the *deviation ratio* into a *disturbance ratio*. The concept of *disturbance ratio* will be discussed in greater detail in the second part of this article.

Figure 2 shows an example of a furnace-control system in an oil refinery, including the plant records of disturbances (Figure 2A), *deviation ratio* plotted against frequency of sinusoidal disturbance (Figure 2B), and the measuring set-up used in gathering the information (Figure 2C).

It appears in Figure 2B that a resonance peak roughly characterizes this typical deviation-ratio curve. This illustrates the influence of frequency on *deviation ratio*. The whole frequency range divides into three significant zones:

LOW FREQUENCY ZONE—For frequencies

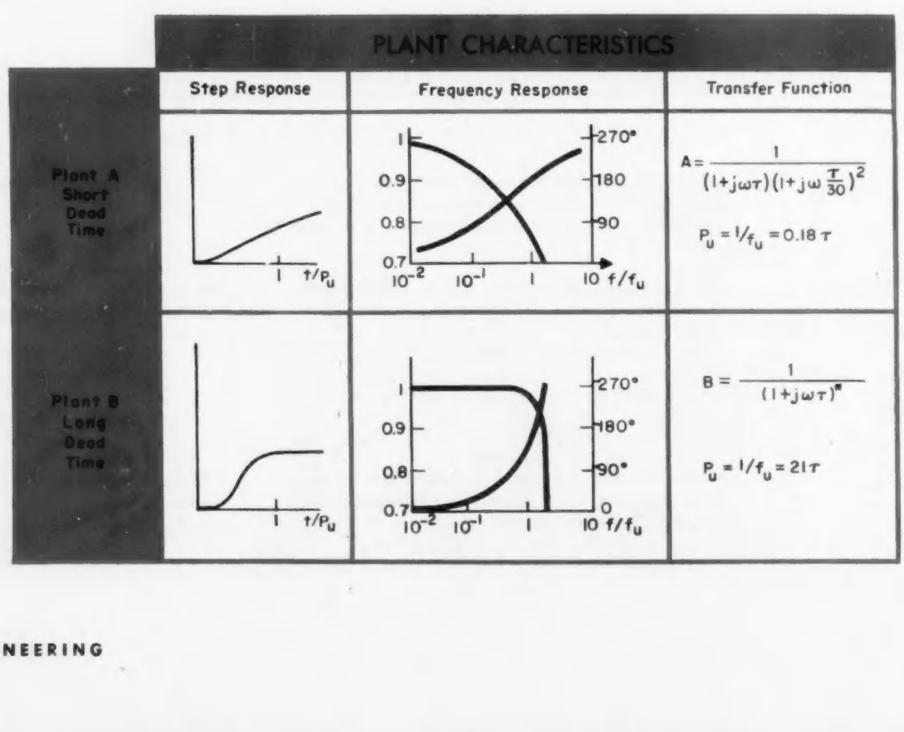


FIG. 3. The dynamic response of two different plants are plotted in non-dimensional form to aid in comparison of their characteristics. Although Plant A has a short dead time and Plant B a long dead time, their deviation ratios appear to be very similar. However, investigation of the low-frequency portions will distinguish the two systems in a more accurate light.

much lower than the resonance frequency the control-valve movement affects the controlled variable fast enough to reduce the resulting deviation. That is, the *deviation ratio* is significantly less than unity.

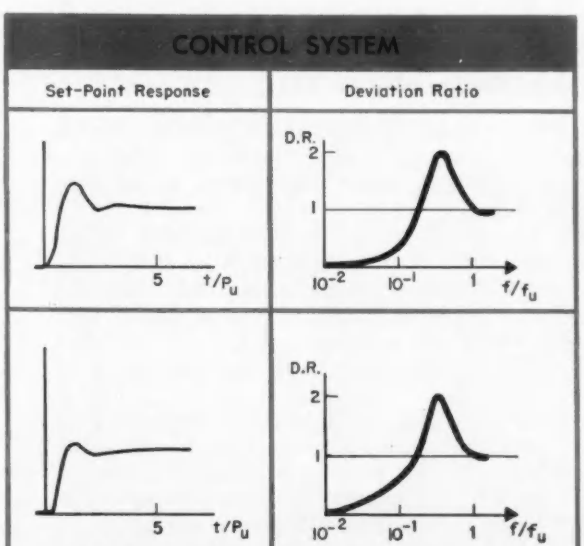
RESONANCE FREQUENCY ZONE—For frequencies around the resonance frequency, the effect of the control-valve movement is so much delayed in the plant that it arrives about a half-period too late. This delay aggravates the effect of the disturbance so that the *deviation ratio* becomes larger than unity in this zone.

HIGH FREQUENCY ZONE—For frequencies much higher than the resonance frequency the plant attenuates the effect of the control-valve movement to the extent that the disturbance remains practically unaffected. Although the deviations with and without control both become small, the *deviation ratio* approaches unity at these higher frequencies. Therefore, no benefit derives from automatic control in this zone.

In the lower frequency zone automatic control serves its purpose well. However the law formulated by Westcott[2]:

$$\int_0^\infty \log \text{deviation ratio } df = 0$$

stipulates that deviation reduction in the low frequency zone must be paid for in the second zone where resonance occurs. That is, the logarithm of the *deviation ratio*, linearly averaged over the whole frequency range, must equal zero. Improvement in one zone sacrifices performance in another zone.



Deviation Ratio and Plant-Controllability

It becomes clear that the resonance frequency roughly characterizes the deviation-ratio curve. The peak height might be included, but this is of little importance in the present discussion. Controller settings influence peak height, but peak height has little to do with plant properties. Thus, changing the proportional band of the controller alters the peak height, but does not change the resonance frequency significantly.

Therefore, the resonance frequency is descriptive of controllability:

- High resonance frequency means high speed of control.
- Low resonance frequency means low speed of control.

The Ziegler and Nichols[3] *ultimate frequency*, f_u, characterizes the plant. If a controller has *proportional plus reset action* only, then a normal controller setting and a normal plant produce a resonance frequency about one-half of the *ultimate frequency*. This describes the speed of control that can be obtained with *proportional plus reset action*.

Figure 3 shows the deviation-ratio curves of two plants that have entirely different responses to a step-change disturbance. The first response has little *dead time* and allows a high proportional gain. The second has much *dead time* and requires a low proportional gain. In spite of this difference the deviation-ratio curves differ very little. Accordingly, the responses to a sudden set-point change are not much different either; the frequency of oscillation of these responses roughly equals the resonance frequency; and damping relates to the height of the resonance peak.

As yet the difference in controllability commonly thought to exist between plants with and without *dead time* has not shown up in the *deviation ratio*. However, the foregoing discussion was based on an important restriction: that the controller included *proportional plus reset action*. On the other hand, the addition of *rate action* could shift the resonance frequency appreciably. Plants that seem equally controllable with *proportional plus reset action* in the controller may well exhibit a clear difference in controllability if *rate action* were added. This latter effect will be discussed in greater detail further on in this article.

But, even if there is no *rate action*, the common belief that *dead time* impairs control should find some confirmation in the deviation-ratio curve. Now it makes little difference to the deviation with control whether, at the resonance frequency, the *deviation ratio* is 2.01 or 2.05. However, five times as much deviation may be left if the *deviation ratio* in the low-frequency zone increases from 0.01 to 0.05. Thus the low-frequency zone has to be scrutinized more closely than is possible solely on the basis of a rough characterization of the deviation-ratio curve. The conclusion to this article, next

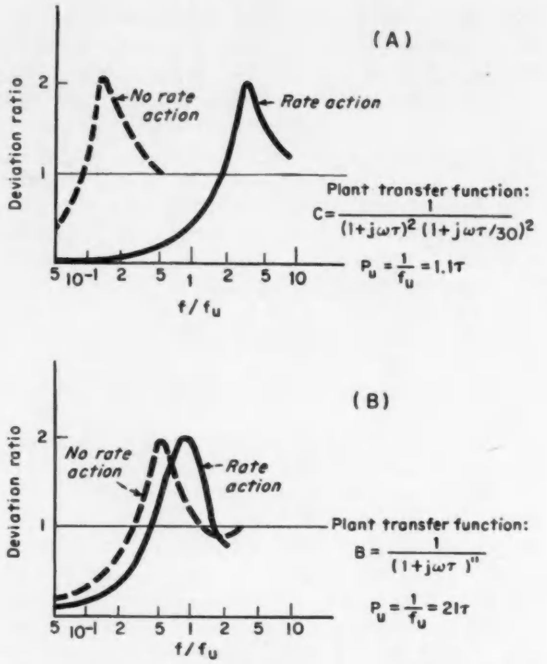


FIG. 4 When a plant transfer function contains two major time constants and two smaller ones, rate action has a great effect on shifting the resonance frequency to a higher value (A). But when the transfer function consists of many cascaded equal time constants, rate action is only slightly effective in increasing the resonance frequency (B).

month, investigates the low-frequency behavior, as well as response to ramp and step change disturbances.

Rate Action and Controllability

In a particular plant-control system, Figure 4A, resonance frequency increases greatly when the controller provides the proper amount of *rate action*. Yet, no appreciable increase in resonance frequency occurs with *rate action* in another plant (Figure 4B). What is the plant characteristic that determines whether or not *rate action* can have a great effect?

To get the answer, go back to the case of *proportional plus reset action*. Here, resonance frequency occurs at a frequency at which the plant phase lag is some tens of degrees less than at the *ultimate frequency*, f_u. At f_u the phase lag is 180 deg. Adding *rate action* shifts the resonance peak to a frequency where the plant phase lag is some tens of degrees less than 270 deg. Therefore:

- The higher the ratio between the frequencies of 270 and 180 deg *plant* phase lag, the more effective the *rate action*.

An indication that supports the above is found in the value of the resonance frequency without *rate action* compared with the *ultimate frequency*, as in Figure 4A. Here, the first is much lower than the second, when compared with the usual factor of about one-half.

The *rate-action* aspect of controllability has been discussed in the *frequency domain*. However, it is also possible to consider this aspect in the *time domain*—in particular, to correlate *rate-action* effect to *dead time* of the plant response. Therefore, some general rules result—

The effect of *rate action* is:

- High when two major time constants plus a number of smaller ones in the transfer function represent the plant response (plant transfer function in Figure 4A).
- Low when a large number of equal time constants represent the plant response (plant transfer function in Figure 4B).
- Lowest in the limiting case of *pure dead time*.

Adding Proportional to Reset

A situation analogous to the above arises when *proportional action is* added to *reset action*. With pure *reset* (integral, proportional speed floating) *action* the plant phase lag is 90 deg at the "ultimate frequency" (limit of stability). For *proportional action* the ultimate frequency corresponds to 180 deg plant phase lag. Thus, as far as *proportional action* is concerned, the ratio between the 180 deg and the 90 deg frequencies becomes the important factor.

- The ratio is high when one major time constant plus a number of small ones represent the plant response.
- The ratio is lowest for a plant with only *pure dead time*. This again ties in with the familiar aspect of *dead time*.

Controllability Not An Absolute Concept

Plant controllability, therefore, is not an absolute concept. Controllability becomes something relative, dependent, among other things, on the available controller actions. In fact, ideal control for any process can theoretically be attained with a controller having a transfer function that is the inverse of the process transfer function. Ideal control is defined as infinite speed of control and infinite resonance frequency, no deviations left. But practical considerations limit the attainment of ideal control:

- The inverse of *dead time* would require an ideal predictor. Such a predictor is not of this world.
- Noise, in the form of mechanical vibrations, disturbs measurement and control equipment. Already a nuisance with normal rate action, it would be even worse with an "inverse-plant-

response" controller that needs higher derivative actions.

► Available power, too, has its limitations. For instance, in temperature control, heat input is, and must be, limited. But with a very lively "inverse-plant-response" controller heat input has no limiting effect on control so long as the disturbances are sufficiently small and slow to keep the valve within its operating range. However, with larger and faster disturbances, such a controller forces the valve to jump from the open to the shut position and vice versa. Thus it would have two-position control instead of the smooth action desired.

► Finally, "inverse-plant-response" controllers require special skill for their adjustment and for keeping this adjustment when the plant response changes. Dead zone effects would have to be avoided, since they negate benefits obtained from higher derivative actions. This article concludes in the December issue.

REFERENCES

1. *CONTROL-SYSTEM BEHAVIOR EXPRESSED AS A DEVIATION RATIO*, by J. M. L. Janssen, Trans. ASME, vol. 76, 1954, pp. 1303-1312.
2. *THE DEVELOPMENT OF RELATIONSHIPS CONCERNING THE FREQUENCY BANDWIDTH AND THE MEAN SQUARE ERROR OF SERVOSYSTEMS FROM PROPERTIES OF GAIN-FREQUENCY CHARACTERISTICS*, by J. H. Westcott, "Automatic and Manual Control", Butterworth Publications, London, England, 1952, pp. 45-64.
3. *OPTIMUM SETTINGS FOR AUTOMATIC CONTROLLERS*, by J. H. ZIEGLER and N. B. NICHOLS, Trans. ASME, vol. 64, 1942.

FIVE PRACTICAL EXAMPLES . . .

. . . show the origin of the three plant transfer functions

a contribution by

A. RUSSELL AIKMAN

Schlumberger Instrument Company

Mr. Aikman has generously provided these examples of plants represented by the three transfer functions used in Mr. Janssen's article. Generally, it is not easy to find plants with such simple transfer functions. In practice, nearly all processes show phase lags in excess of those accounted for by any combination of exponential lags, because most real plants have either transport lags or distributed parameters.

PLANT A

$$\frac{1}{(1+j\omega T)\left(1+\frac{j\omega T}{30}\right)^2}$$

One exponential time lag of unity time constant cascaded with two lags of time constant 1/30.

PLANT B

$$\frac{1}{(1+j\omega T)^{11}}$$

An exponential lag of unity time constant cascaded eleven times.

PLANT C

$$\frac{1}{(1+j\omega T)^2\left(1+\frac{j\omega T}{30}\right)^2}$$

Two cascaded exponential lags of unity time constant, cascaded with two lags of time constant 1/30.

In the transfer function representations of three types of plants, on the preceding page, each factor derives from separate energy-storage elements. The time constant, T, is the product of the resistance and capacity in element, or T equals RC. The transfer functions assume that each element is isolated from all of the others. That is, the elements are non-interacting; an example of this occurs when the level of one tank does not affect the level in an adjacent tank, or

$$\frac{1}{(1 + j\omega T_1)\ (1 + j\omega T_2)} \qquad (1)$$

where $T_1 = R_1C_1$ (tank 1) and
$T_2 = R_2C_2$ (tank 2).

If the level of one tank does affect the other, the resultant interaction requires a more complicated transfer function of the form.

$$\frac{1}{(R_1C_1 + R_2C_2)\ (j\omega)^2 + (R_1C_1 + R_1C_2 + R_2C_2)\ j\omega + 1} \qquad (2)$$

However, when the second tank does not significantly "load" the first tank the system becomes non-interacting. This means that, in general, C_2 is much smaller than C_1 or R_2 is much greater than R_1 and Equation 2 approximates Equation 1. But, in the intermediate case, where C_2 and C_1 (or R_1 and R_2) are of the same order of magnitude, the transfer function can still be represented by a two-factor transfer function.

$$\frac{1}{(1 + j\omega T_a)\ (1 + j\omega T_b)} \qquad (3)$$

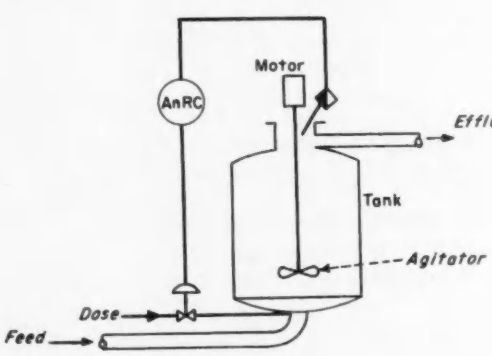
In Equation 3, T_a and T_b relate to R_1C_1 and R_2C_2. The equations for T_a and T_b can be found from the denominator of Equation 2. Can you determine the relationships? Hint: use the quadratic formula.

REFERENCES

1. *DETERMINATION OF MINIMUM CAPACITIES FOR CONTROL APPLICATIONS*, by F. W. Velguth and R. C. Anderson, ISA paper 53-6-3.
2. *DETERMINE SYSTEM DYNAMICS WITHOUT UPSET*, by J. B. Reswick, CONTROL ENGINEERING, June 1955, pp. 50.
3. *A SYSTEMS ANALYSIS PREDICTS PERFORMANCE*, by G. J. Fiedler, T. F. McGrath, and A. E. Buescher, CONTROL ENGINEERING, July 1955, pp. 65.
4. *AUTOMATIC CONTROL OF A PRESSURE PROCESS*, N. H. Ceaglske and D. P. Eckman, "Industrial & Engineering Chemistry", 1953, pp. 1879.

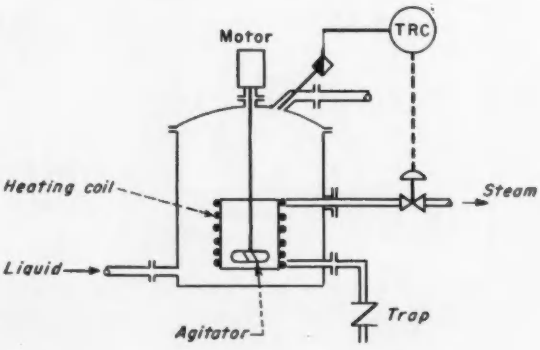
PROCESS 1

A concentration control system[1], at right, describes a typical **Plant A.** The residence time of the liquid in the tank produces the major time lag which may be some minutes. In addition, the first of the minor lags is due to the finite time required to disperse any portion of the feed throughout the fluid in the tank. For extremely good agitation, this lag will be a fraction of a minute. The second minor lag, of the same magnitude, results from the inherent lag in the response of the sensing element. The small lag assumes sensing element immersion near the vicinity of the overflow. But an external sampling system would introduce a transport lag (dead time). Control valve lag is neglected.



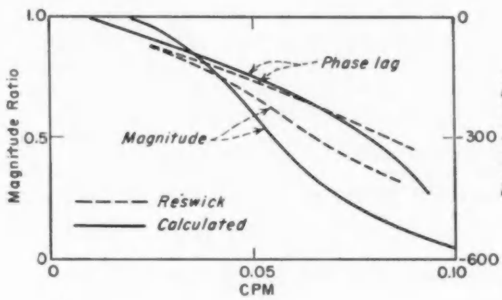
PROCESS 2

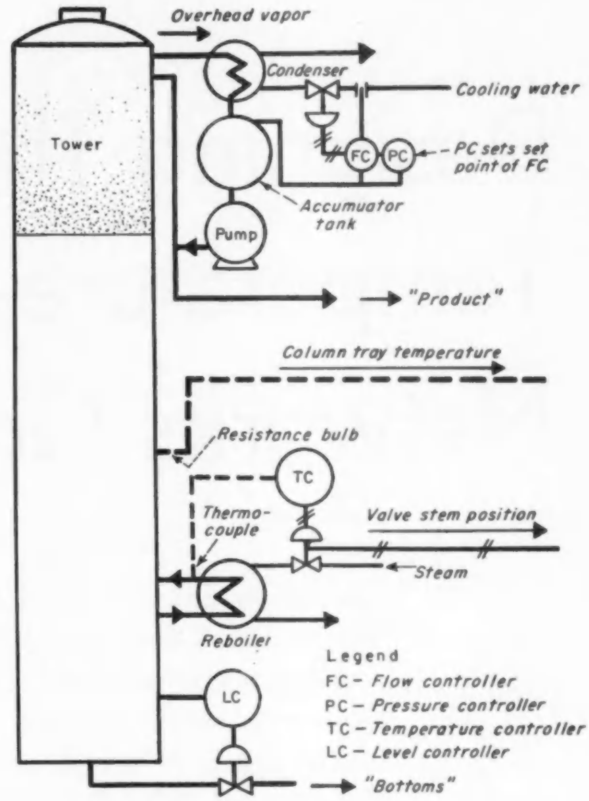
The simple steam liquid process heater at right represents another plant typical of the characteristics of Plant A. Here it is desired to control the temperature of the system. Assume the system has lumped parameters—that is, in this case the fluid is well agitated. The major time lag (perhaps a few minutes) and one of the minor lags (fraction of a minute) associate with the heater itself. The heater, therefore, is assumed to have two energy-storage components: the liquid and the metal in the coil. The heat capacity of the steam in the coil and the control valve lag are neglected. The second minor lag comes from the temperature sensing element.



PROCESS 3

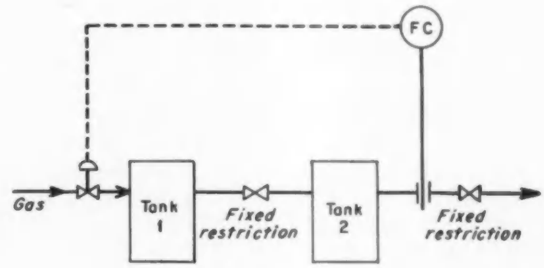
Transfer functions of the Plant B type are sometimes associated with fractionating columns (right). For example, the column described by Reswick[a] has a transfer function (tray temperature/steam valve position) of this type. In the figure below the solid lines represent the frequency response characteristics determined by Reswick in his correlation studies. Superimposed on this response are the results (dashed lines) calculated from the transfer function of Plant B with T equal to 0.92 min. The phase lag is in fair agreement, but the calculated magnitude ratio differs at some frequencies from the values found by Reswick. Closer correspondence with magnitude ratio is obtained if the number of lags increases, but then the calculated phase lag is in excess of Reswick's values.





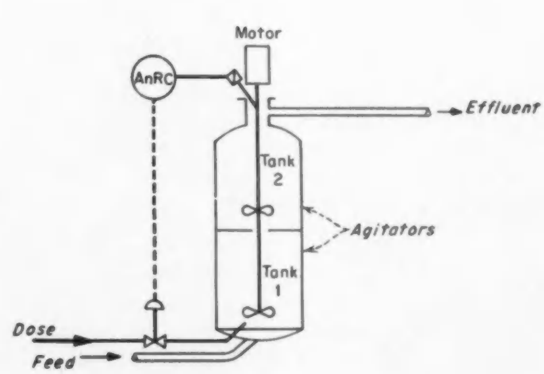
PROCESS 4

A gas flow control system, at right, with two non-interacting capacity-resistance combinations, typifies Plant C. Non-interaction assumes the pressure drop in the restriction between tanks is over-critical. The two major time constants derive from the two tanks and the two fixed restrictions, the first tank receiving gas from a constant pressure source. The tank lags may be calculated by methods given in references 3, 4. The two minor lags, of approximately equal magnitude, represent the control valve and a mercury-manometer flow measuring instrument. Lags due to transmission become negligible, under the assumption that electrical transmission and control are used, or that if a pneumatic system is used the elements are close-coupled.



PROCESS 5

Another example of the Plant C transfer function is shown at the right. This concentration control system comprises two essentially isolated tanks, as compared with the one tank system in Process 1. It is this second tank that contributes the second cascaded major time constant in the transfer function for Plant C arrangements. The smaller time constants come from the lag in the sensing element and the dispersal time of fluid in the bodies of the tanks.



Designing Thermistor Temperature-Correcting Networks Graphically

Component accuracy can be affected by the resistance variation of copper conductors with temperature. One way to compensate for the change in resistance is to use a thermistor network in series with the conductor. This solution was treated briefly in Compensating Instruments for Temperature Changes, CONTROL ENGINEERING, May 1955. This expanded discussion also describes a graphical method for quickly determining the correct thermistor network.

FRANK BENNETT, Thermistor Corp. of America

Copper has a positive temperature coefficient of resistance of about 0.39 per cent per deg C at a temperature of 25 C. Thus the resistance of a copper coil can change by as much as 50 per cent over the temperature range required in some military specifications. This affects the accuracy and performance of such devices as meters, magnetically actuated transducers, synchros, resolvers, motors, and transformers. To reduce the effect of temperature variations, some compensating system must be used.

For copper, the corrective device should exhibit a straight-line resistance-temperature characteristic to perfectly cancel the variations in resistance. The corrective device then can be put in series with the copper coil so that the resultant total circuit resistance remains constant. Since the temperature coefficient of copper is positive (resistance increases with increasing temperature), the corrective device must have a negative temperature coefficient of resistance. One such device is the thermistor (thermally sensitive resistor).

Thermistors have a high negative temperature coefficient of resistance; about ten times that of copper. This means that a low resistance thermistor can cancel the variations of a high resistance copper coil without excessively increasing the overall circuit resistance.

One apparent disadvantage of the thermistor is that its resistance-temperature characteristic is very nonlinear over reasonably wide ranges of temperature, Figure 1. However, the linearity of a thermistor can be improved by shunting it with a fixed resistor. The resultant compensator (shunted thermistor) has a nearly linear characteristic over a wide temperature range.

The effective coefficient of such a compensator, although less than that of a thermistor alone, is still very high. The overall circuit resistance of copper plus compensator over the normal room temperature range can be held to plus or minus 0.1 per cent, while over a military specification temperature range, the maximum resistance variation can usually be limited to plus or minus 1 per cent.

The design of this type of compensator does not

lend itself to straightforward mathematical techniques. No unique solution is obtained by equating mathematically the slopes of the coil and the compensating circuits, since the shunting resistor has introduced another variable. However, the graphical method described below permits quick and accurate design of the compensating circuits for the best fit over a whole range of temperatures. Actually the graphical technique is used primarily to determine the proper ratio between the shunt and thermistor values. The specific magnitude can then be determined by simple arithmetic.

Figure 2 shows the resistance of several compensators (shunted thermistors) as a function of temperature. In each case the value of the shunt resistor is taken as 1 ohm. Curves are shown for thermistor resistances of 0.4, 0.6, 1, 1.4, and 2.4 ohms at 25 deg C (77 F). The temperature coefficient of the thermistor is chosen as minus 3.86 per cent per deg C (at 25 C) for this reason: this coefficient is a property of thermistors made of the minimum resistivity material in the manganese-nickel-cobalt oxidic system; available from several manufacturers, they are very stable and

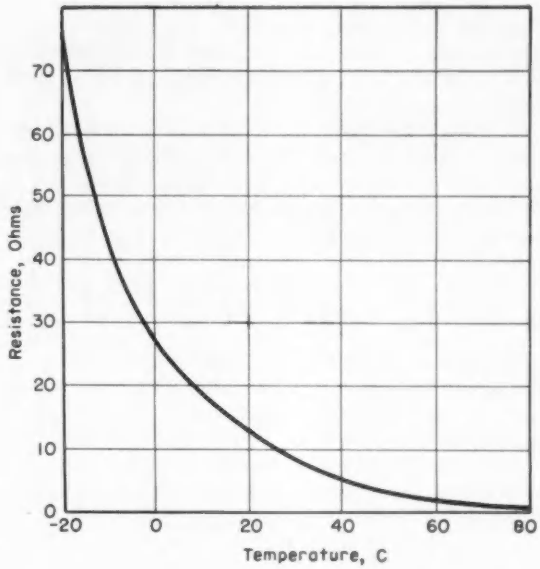
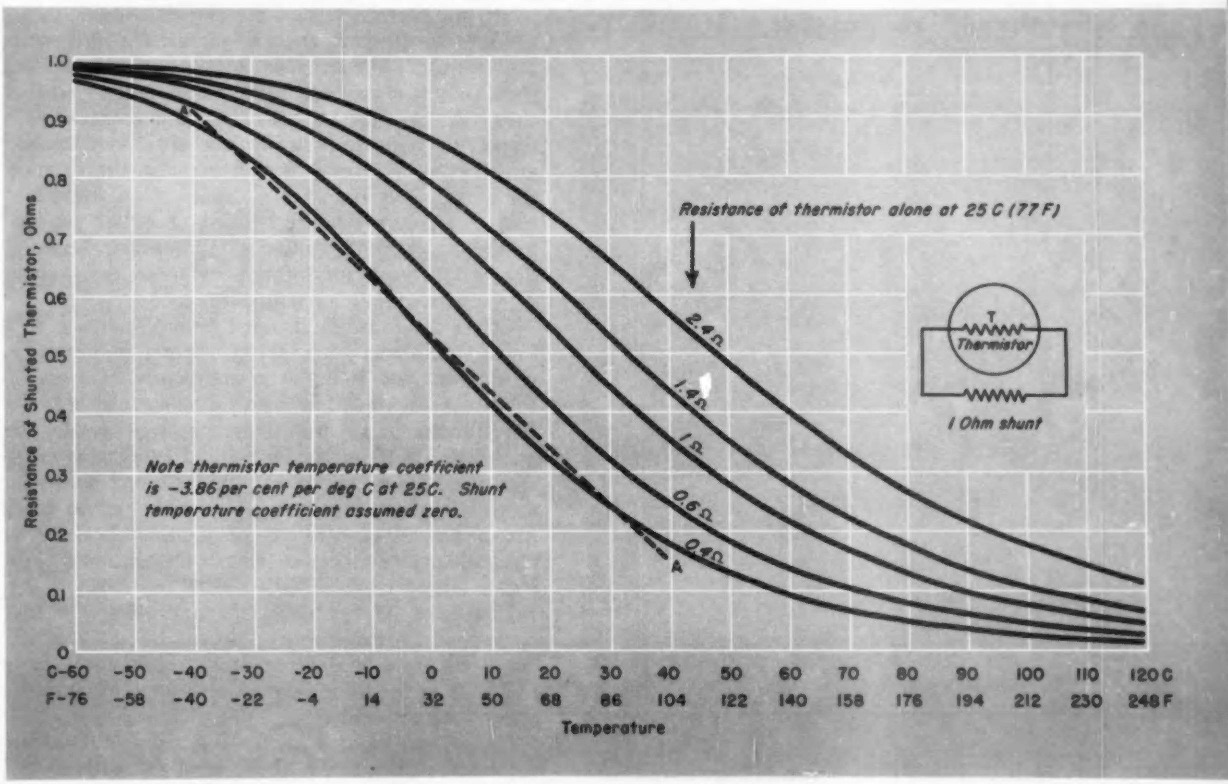


FIG. 1. Resistance versus temperature characteristics of a typical thermistor.

FIG. 2. Resistance of shunted thermistor-versus-temperature for 1 ohm shunt and various thermistor resistances.



have a convenient resistivity for compensating applications. This will probably be the material used, except in rare instances involving either very low or very high resistances.

To apply the graphical method, the temperature range for compensation must be known. Do not arbitrarily choose a range wider than necessary. An optimum design for an unnecessarily wide range will not give the best possible design for the narrower range that will actually be used.

USING THE GRAPH

Assume a copper coil must be compensated over the range from minus 40 to plus 40 deg C. The first step is to construct the straight line on Figure 2 that comes closest to fitting one of the given curves over the temperature range. In this case the lowest curve gives the best fit, resulting in straight line A–A. In general, a good fit yields three points of intersection with the straight line. The maximum deviations at the ends and at two intermediate temperatures should be equal.

This straight line represents the average performance between minus 40 and plus 40 deg C of a thermistor (whose resistance at 25 C is 0.4 ohms) shunted by a 1 ohm resistor. This is the tentative compensator whose values will finally be multiplied by an appropriate factor to produce the desired resistance change, ΔR, over the full temperature range. The change of resistance of the line A–A between minus 40 and plus 40 deg C is 0.755 ohms (0.92 minus 0.165).

If the coil to be compensated has a resistance of 100 ohms at 25 deg C, then the change in resistance over the specified range of 80 deg C is

$$\Delta R = 100(80)(0.0039) = 31.2 \text{ ohms}$$

The change in resistance of the compensator should also be 31.2 ohms over this range. Since the desired ΔR is 31.2 ohms, and the ΔR of the tentative compensator selected above is only 0.755 ohms, the compensator values must be scaled up proportionately to provide the desired ΔR. Multiplying the tentative compensator values by

$$\frac{31.2}{0.755} = 41.4$$

will give the required compensator values. Thus, the shunt resistance should be 41.4 ohms, and the thermistor resistance at 25 deg C should be (0.4)(41.4) or 16.5 ohms. This completes the compensator design.

Additional calculations can be made to determine the (constant) resistance of the coil-plus-compensator and the residual variation in resistance.

The line A–A represents about 0.3 ohms at 25 deg C. Thus the total average circuit resistance of the coil plus compensator is

$$100 + 41.4(0.3) = 112.4 \text{ ohms}$$

The total resistance will vary slightly about this average value over the temperature range. The maximum deviation of A–A from the curve is 0.025 ohms. Therefore, the maximum deviation of the coil-compensator combination from the average is

$$0.025(41.4) = 1.0 \text{ ohm}$$

(or about 0.9 per cent) and occurs at about minus 40, minus 20, plus 15, and plus 40 deg C.

This method will generally yield the best linearity for the given original choice of thermistor temperature coefficient. In some applications, it may be necessary (because of the overriding requirement of low overall circuit resistance) to use higher shunt values or no shunt at all. The thermistor itself gives the least overall circuit resistance, but linearity is sacrificed.

If total circuit resistance is not a problem, somewhat better linearity can be obtained by basing the whole design on a lower coefficient thermistor. Although the extreme of just adding additional series zero-coefficient resistance tends to swamp out the resistance variations, it is usually necessary to keep the total circuit resistance as low as possible to reduce power losses. For coil resistance levels much higher than in the above example, even higher coefficient thermistors are available.

SOME DESIGN TIPS

Certain precautions should be observed in applying these compensators. The thermal coupling between the thermistor and the copper coil should be good to insure that they are actually at the same temperature. When close coupling is not possible, the thermistor and coil should be mounted so that they both have the same thermal time constant with respect to changes in temperature of the surrounding air. Intimate thermal contact between the thermistor and coil is almost a necessity if an important part of the temperature change of either the coil or the thermistor is caused by the electrical current flowing in the circuit and not merely by the changes in the surrounding air temperature.

Other design methods must be used when a non-linear resistance-versus-temperature characteristic is required; for example, in compensating a phototube. Again, a good fit (three intersections between the desired and actual curves), can usually be achieved. Both in the linear and non-linear cases, additional intersections can be obtained by using more complicated compensators with two or more thermistors. These might be required because of unusual accuracy specifications or an extremely wide temperature range.

The aging, or change in characteristics with life, of a good thermistor in compensator service will not normally exceed 1 per cent. This corresponds to a shift in the overall circuit resistance of, at most, about 0.05 per cent.

Copies of Figure 2, showing more thermistor resistance values, are available from the author.

Design Regulating Systems By Error Coefficients

THE GIST: Unlike a slave system, which must closely follow its input signal, a regulating system must not follow its input, which is usually a disturbance or change in load. Most of the techniques used to analyze regulating systems were first developed for slave systems and use system response to step inputs. If sudden changes of load are common, this is reasonable. But if, as is often true, the system is subject to a varying load that does not change abruptly, a technique based on a gentler input is more logical.

The method of error coefficients is based on the assumption of an input that varies smoothly. Its techniques are partly mathematical, partly graphical. They are described here in detail and illustrated by three examples each on two kinds of plants.

PAUL E. SMITH, JR.,

Massachusetts Institute of Technology

If an input disturbance varies smoothly, i.e., if it and its derivatives have no discontinuities, it will cause an error that can be expressed as:

$$E(t) = a_o\, D(t) + a_1\, dD/dt + a_2\, d^2D/dt^2 + \cdots \qquad (1)$$

where

$E(t)$ is the error as a function of time
$D(t)$ is the disturbance as a function of time
$a_o, a_1, a_2, \ldots$ are error coeff cients

The transfer function relating the error to the disturbance can be stated also as a fraction of two polynomials:

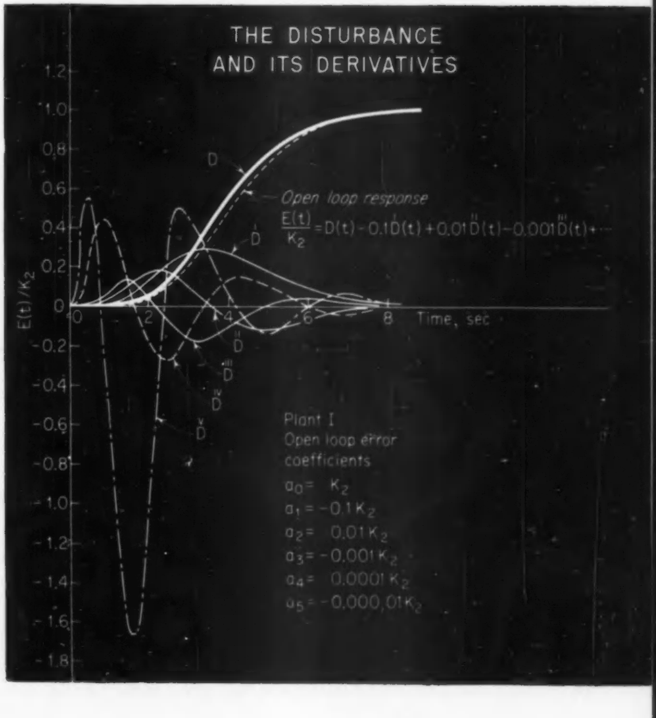
$$\frac{E(s)}{D(s)} = \frac{n_o + n_1 s + n_2 s^2 + n_3 s^3 + \cdots}{1 + d_1 s + d_2 s^2 + d_3 s^3 + \cdots} \qquad (2)$$

The error coefficients of Equation 1 are related to coefficients n and d of Equation 2 as follows:

$$\begin{aligned} a_o &= n_o \\ a_1 &= n_1 - a_o d_1 \\ a_2 &= n_2 - a_o d_2 - a_1 d_1 \end{aligned} \qquad (3)$$

$$a_k = n_k - \sum_{j=0}^{j=k-1} a_j d_{k-j}$$

FIG. 1



There are other forms for evaluating the a's, but the formulas of Equation 3 are convenient.

If the parameters of a system are known numerically, it is possible to calculate values for the n's and d's. Then the a's can be computed by substituting them in Equation 3.

SYNTHESIS PROCEDURE

To use the method of error coefficients for regulating system synthesis, the gains and time constants of the process or plant to be controlled must be known. The general kind of controller may be selected previously, but values for its time constants (or reset times) and its gains (or proportional bands) still must be found. Thus they are specified literally. To evaluate the a's, combine the numerical data about the process and the literal data about the controller, leave the higher-order a's in terms of the lower-order a's and the n's and d's of Equations 1 and 2.

Find a typical disturbance, $D(t)$, for the process by test or calculation. Graph it and several of its derivatives. By inspecting the derivatives and their maxima, and the times of occurrence of their maxima, values can be estimated for the error coefficients that will meet any specified maximum error.

The first error coefficient depends upon system gains only and its specification fixes the gain. The other coefficients depend upon controller and load time constants. Because acceptable numerical values have been found for the a's, the controller time constants can be evaluated. If the controller chosen originally cannot meet the specifications, try another.

Although not mentioned so far, system stability constrains design. The usual stability criteria should be followed during design by error coefficients. This limits the range of choice for controller gains and time constants, making it more difficult to realize the specified a's.

Several examples that follow illustrate the use of error coefficients for analysis and synthesis. Two systems, a pneumatically controlled heat exchanger and an electrically controlled speed system, are used for the sake of variety.

The same disturbance is assumed for all of the examples (for convenience only). It is illustrated in Figure 1 with its first five derivatives.

TWO PLANTS FOR EXPOSITION OF TECHNIQUE . . .

PLANT I

a pneumatically controlled heat-exchanger

A pneumatic valve in a steam line controls a heat exchanger. The air line has resistance and capacitance. The valve has pneumatic capacitance plus a capacity effect due to the changing volume as the valve spring compresses to close the valve. The literal expressions for parameters are given on Figure 2A. Figure 2B diagrams the penumatic system.

The heat exchanger dynamics are simplified by assuming that steam flow through the exchanger changes immediately when the valve motion occurs. Assume also that the principal heat source is from condensation and that the temperature of the load side is low enough so that the steam is a heat source H_{in} proportional to steam flow, which is proportional to valve position.

If load flow is Q_L and the specific heat of the load is s_h, then:

$$H_{in} = C_t\, dT/dt + Q_L s_h (T + T_o)$$

where T_o and T are the temperatures of the entering and leaving load flows. Or:

$$H_{in}/s_h Q_L + T_o = \frac{C_t}{Q_L s_h}\, dT/dt + T$$

Defining C_t/Q_L as T_3, the usual form results. Figure 2B.

PNEUMATIC CIRCUIT FOR LINE AND MOTOR (PLANT I)

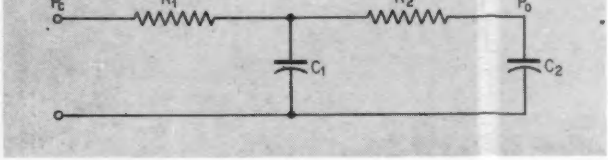
$$C_1 = \frac{C_L}{2}$$

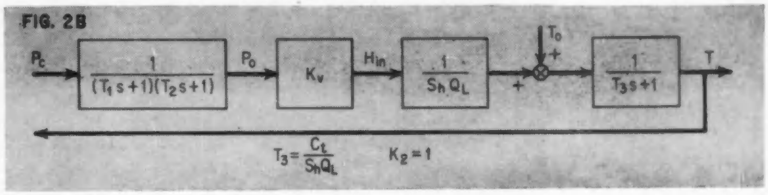
$$C_2 = \frac{C_L}{2} + \frac{V_v}{P_{aa}} + \frac{A^2}{K}$$

$$R_1 = R_2 = \frac{R_L}{2}$$

P_c – controller output pressure
P_o – valve motor pressure
R_L – resistance of line
C_L – capacitance of line
V_v – volume of valve motor
P_{aa} – average absolute pressure
A – area of valve motor diaphragm
K – valve motor spring constant

FIG. 2A





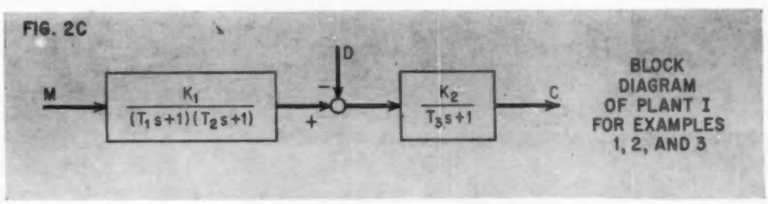
T_1 and T_2—Time constants of the pneumatic network of Figure 2A. T_1 is greater than the larger of R_1C_1 and R_2C_2; T_2 is smaller than the smaller.
K_v—a valve constant relating heat into exchanger to pressure on valve motor.
s_h—specific heat of load material
Q_L—load flow

C_t—thermal capacity load side
P_c—manipulated variable (M in examples)
T—the controlled variable (C in examples)
$-T_o$—the disturbance (D in examples)

$\frac{K_v}{s_hQ_L}$—defined as K_1

Time constants are arbitrarily considered to be:

$T_1 = 1$ sec
$T_2 = 0.3$ sec
$T_3 = 0.1$ sec

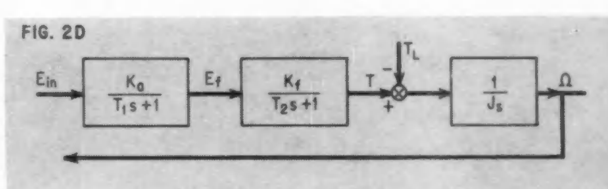


PLANT II

a speed control system

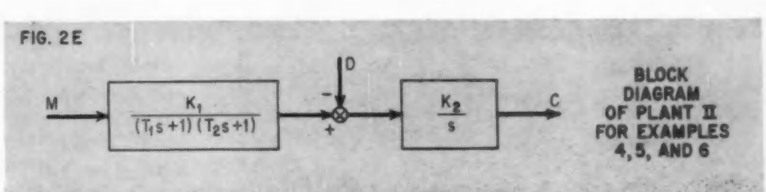
The second plant is a speed control system using a dc motor with constant armature current and controlled field current. Assume that the load is inertia only. Assume also that the two lags shown are associated with the amplifier, including that of the motor-field inductance-resistance ratio. The block diagram used is shown in Figure 2E. The torque transmitted to the load is shown.

K_a—amplifier gain
K_f—motor gain relating torque to field voltage
T_1—time constant associated with amplifier
T_2—time constant associated with motor field
J—inertia of motor and load
E_{in}—manipulated variable (M in examples)
Ω—speed-controlled variable (C in examples)
T_L—load torque—the disturbance (D in examples)
K_aK_f—defined as K_1
$1/J$—defined as K_2



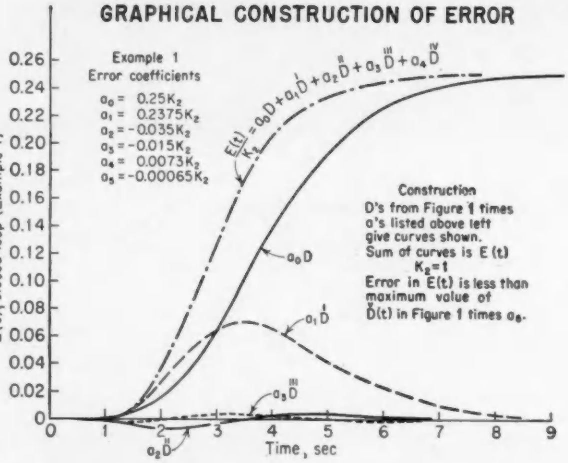
Time constants are arbitrarily considered to be:

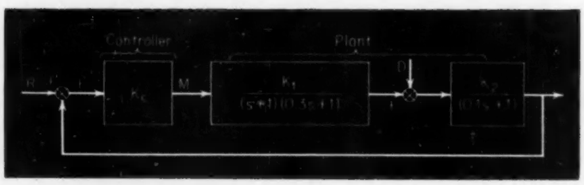
$T_1 = 0.1$ sec
$T_2 = 0.02$ sec



SIX EXAMPLES FOLLOW . . .

EXAMPLE 1—Analysis of Plant 1 with Proportional Control.





Adding a simple proportional controller to Plant I and closing the loop gives the block diagram at left. If subjected to a disturbance $D(t)$, the literal expression for $E(s)/D(s)$ for this closed loop is:

$$\frac{E(s)}{D(s)} = \left[\frac{1}{1+K}\right]\left[\frac{(T_1s+1)(T_2s+1)}{\frac{T_1T_2T_3}{1+K}s^3+\frac{T_1T_2+T_1T_3+T_2T_3}{1+K}s^2+\frac{T_1+T_2+T_3}{1+K}s+1}\right]$$

where

$$K = K_1K_2K_c$$

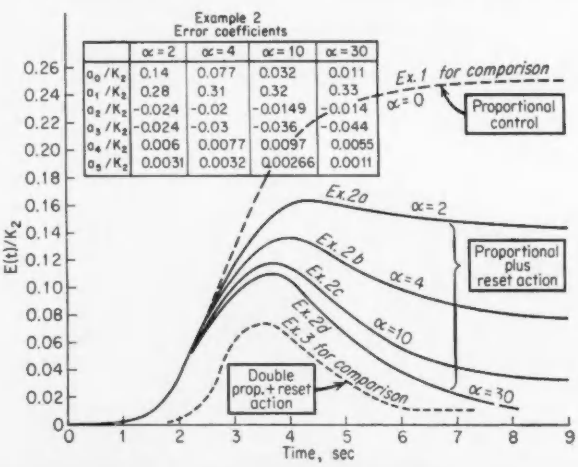
For reasonable stability, the loop gain can be about T_1/T_2, or 3.0. Substituting this value, and the time constants for Plant I (Figure 2C) in $E(s)/D(s)$ leads to these values for the n's and d's:

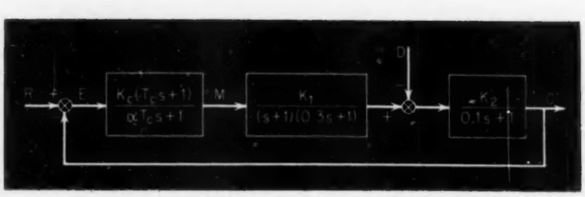
$$\begin{array}{ll} n_o = 0.25K_2 & d_o = 1 \\ n_1 = 0.325K_2 & d_1 = 0.35 \\ n_2 = 0.075K_2 & d_2 = 0.1075 \\ n_3 = 0.0 & d_3 = 0.0075 \end{array}$$

Substituting the n's and d's in the formulas of Equation 3 yields the a's in the graph at left.

This graph shows how the error is constructed from the disturbance of Figure 1 and the error coefficients for this example. Note that as K_2 becomes smaller, the load disturbance has less effect; i.e., regulation is better. K_2, fixed during design, can be removed. Thus the graph is a plot of $E(t)/K_2$.

EXAMPLE 2—Plant 1 with Proportional Plus Reset Control





In the block diagram a loop is closed around Plant I and a proportional plus reset action controller. This should reduce the effect of steady loads. From the block diagram:

$$\frac{E(s)}{D(s)} = \frac{\dfrac{K_2}{0.1s+1}}{1+\dfrac{K(T_cs+1)}{(\alpha T_cs+1)(s+1)(0.3s+1)(0.1s+1)}}$$

where $K = K_1K_2K_c$

Again for reasonable stability, $K = 3\alpha$ and $T_c = 1$ sec. The time constants of Figure 2C give:

$$\begin{array}{ll} n_o = K_2/(1+K) & d_o = 1 \\ n_1 = K_2(1.3+\alpha T_c)/(1+K) & d_1 = (1.4+\alpha T_c+KT_c)/(1+K) \\ n_2 = K_2(1.3\alpha T_c+0.3)/(1+K) & d_2 = (1.4\alpha T_c+0.3)/(1+K) \\ n_3 = K_2(0.3\alpha T_c)/(1+K) & d_3 = (0.43\alpha T_c+0.03)/(1+K) \\ & d_4 = 0.03\alpha T_c/(1+K) \end{array}$$

The first five error coefficients are listed and plotted for several a's in the graph. The graphical construction is similar to that in Example 1.

Note that the error contributed by dD/dt becomes dominant for α's greater than 5 or 6, and is unaffected by increasing α beyond 10 or so. Example 3, therefore, considers how to reduce the dD/dt term without increasing the other terms that contribute to the error.

EXAMPLE 3—Plant I with Double Proportional Plus Reset Control.

For the fixed T_c in Example 2, a_1 could not be decreased without increasing a_o. Note that T_c must be greater than 1 sec for system stability. Increasing T_c might help. An approximation for $\alpha > 5$ and $T_c > 1$ gives

$$\frac{a_1}{K_2} \cong T_c\left(\frac{1}{3} - \frac{4}{9\alpha}\right)$$

Obviously, increasing T_c is not the answer. A different kind of controller is needed.

Note that an integration of the jth order reduces a_o, a_1, . . . a_{j-1} to zero. In Example 2 the proportional plus reset controller reduced a_o. It acted as an imperfect integrator. It should be possible, then, to reduce both a_o and a_1 by using a controller that approximates a double integration; i.e., a "double-act" controller, two cascaded proportional plus reset controllers connected so the output pressure from the first acts on the receiver of the second. Thus, the block diagram at right.

The n's and d's for this system yield

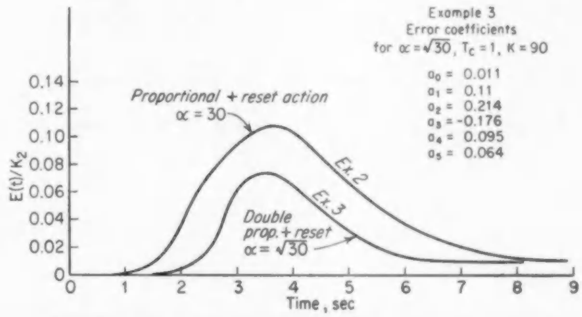
$$a_o/K_2 = 1/(1 + 3\alpha^2)$$

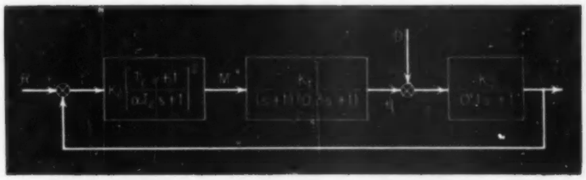
$$a_1/K_2 \cong \frac{6\alpha^3 T_c + 3.9\alpha^2 - 6\alpha^2 T_c - 0.1}{(1 + 3\alpha^2)^2}$$

$$a_2/K_2 \cong \frac{2}{3\alpha} \quad \text{(for large } \alpha\text{'s}$$

upon substitution in Equations 3.

For an actual design problem, a_o/K_2 would be estimated from the allowable maximum error and the $D(t)$ curves. For example, consider that α has a value that gives the same a_o obtained with $\alpha = 30$





in Example 2. Then $a_o/K_2 = 0.011$ and $\alpha = (30)^{\frac{1}{2}}$.

$$\text{and } \frac{a_1}{K_2} = \frac{180T_c(\sqrt{30} - 1) + 117}{91^2}$$

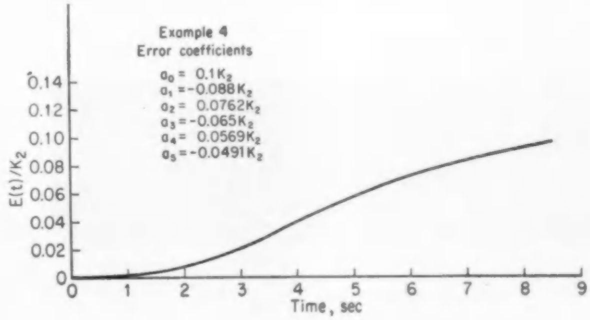
and the best value of T_c is the smallest consistent with reasonable stability. Use 1 sec as before, though the new system is not then quite as stable as that of Example 2.

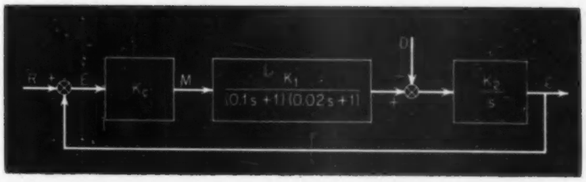
The a's are listed and $E(t)/K_2$ is plotted above Note that the improvement in a_1 is at the expense of a_2, a_3, etc. Thus the improvement in $E(t)$ might not always be as great as expected.

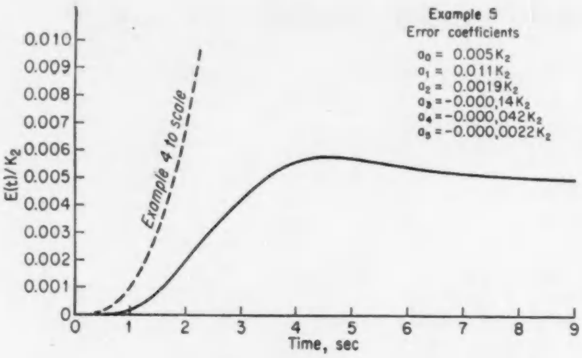
EXAMPLE 4—Plant II with Proportional Control.

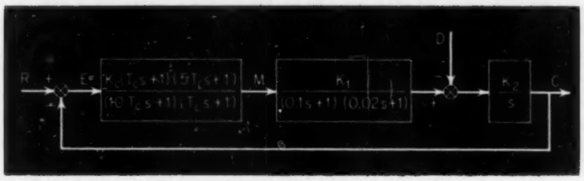
The open-loop speed control "plant" of Figure 2E is closed with a simple proportional controller (diagram). With the parasitic time constants shown, a gain of ten is feasible with stability.

The error coefficients can be calculated and $E(t)$ plotted as in Example 1. Using the same disturbance for convenience, the graph at right results.









EXAMPLE 5—

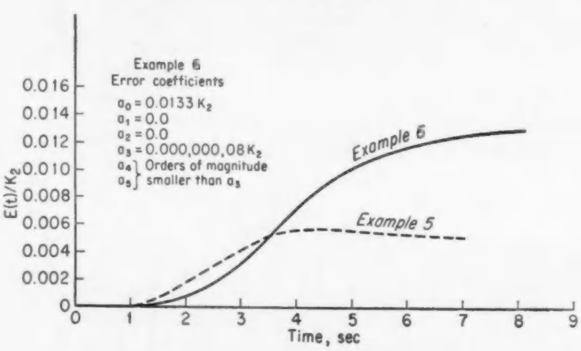
Plant II with Lead-Lag Control.

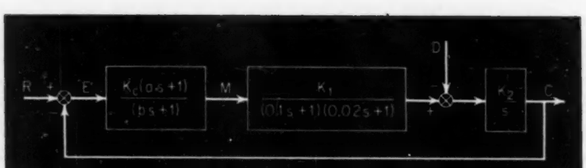
Now consider Plant II in a closed loop with a lead-lag controller (similar mathematically to a three-action, proportional plus reset plus rate, controller), block at left. Because of the integration due to the motor, T_c, T_L and K must be adjusted carefully for stable operation. Reasonable values are $T_c = 0.2$ sec, $T_L = 0.02$ sec, and $K = K_1K_2\ K_c = 200$.

For these conditions and the other time constants shown, the error coefficients are listed, and $E(t)/K_2$ plotted at left. Note the scale change from the graph in Example 4.

EXAMPLE 6—

Plant II with Lead Control.





If the controller is assumed to include a network of fixed form, e.g., the one in the last block has one numerator and one denominator term, the method of error coefficients can be used to specify the time constants (a and b) such that $E(t)$ assumes almost any required form.

For example, for the controller network of this block, values for a and b can be found so that the first and second derivatives of $D(t)$ are zero ($a_1 = a_2 = 0$). At the same time, a_o can be kept small.

This is done by writing the literal expressions for the a's from the equation for the system blocked here. Setting a_1 and a_2 equal to zero, various values are tried for K, and the highest value that gives reasonable time constants is considered the best answer. In this example, for $K = 75$, a_1 and a_2 are zero if $a = 0.03167$ sec and $b = 0.005$ sec. The resultant error coefficients and the error are respectively listed and plotted at left.

There is no particular merit in making a_1 and a_2 exactly zero. A value of 0.001 would be just as useful practically for this example. In any case, drift in parameter values would mean small finite values for the coefficients in actual use.

ACCURACY OF THE METHOD

The effect of higher derivatives of the disturbance has not been mentioned. If the contribution to the error of the nth derivative is calculated, the mistake in neglecting all higher derivatives is no greater than the value of the $(n+1)$th coefficient times the $(n+1)$th derivative.

REFERENCES

1. *REDUCTION OF FORCED ERROR IN CLOSED LOOP SYSTEMS*, L. H. King, "Proceedings of the Institute Radio Engineers", New York, Vol. 41, August 1953, pp. 1037-42.
2. *CLOSED EXPANSION OF THE CONVOLUTION INTEGRAL (A Generalization of Servomechanism Error Coefficients)*, Edward Arthurs and Louis H. Martin, "Journal of Applied Physics", Vol. 26, No. 1, January 1955, p. 58.

Using a Two-Phase Servomotor as an Induction Tachometer

The basic two-phase machine can be used as a servomotor if power is supplied to both phases, or as an induction tachometer if the rotor is driven from an external source and power is supplied to one phase. The output from the motor is torque; from the tachometer, a voltage proportional to speed. Performance is measured by torque per watt and volts per rpm, respectively. The following points out a direct proportionality between these two fundamental figures of merit.

SIDNEY A. DAVIS, Servomechanisms, Inc.

While an induction tachometer's electromagnetic structure is like that of a two-phase servomotor, the tachometer incorporates special design features dictated by accuracy and stability requirements and by an attempt to obtain ideal performance. Thus a conventional two-phase motor can be used as a tachometer only in low accuracy applications. Here a servomotor is cheaper and it is possible to use its parameters to predict the tachometer gradient.

The relation between the gradient and the motor torque per watt can be derived from the equivalent circuit of a two-phase machine shown in the accompanying sketch. For simplicity, the derivation is restricted to the formula for gradient at low speeds ($v<<1$). Also, the turns ratio a is taken as one, so that Z_{l1} and Z_{l2} are equal and can be expressed as Z_l.

Torque can be expressed as a function of resistance, speed, and the rotor currents.

$$T = I^2 \frac{R_R v}{1 - v^2} + \frac{2R_R}{1 + v} I_A I_B \cos\theta\,{}^{I_A}_{I_B} \quad \text{synchronous watts} \qquad (1)$$

or to obtain the torque in oz-in.

$$T = \frac{1352}{\text{Synchronous rpm}(N_s)} \text{(synchronous watts)} \qquad (2)$$

Then at low speeds, Equation 1 reduces to

$$T = 2R_R I_A I_B \cos\theta\,{}^{I_A}_{I_B} \qquad (3)$$

or in oz-in.,

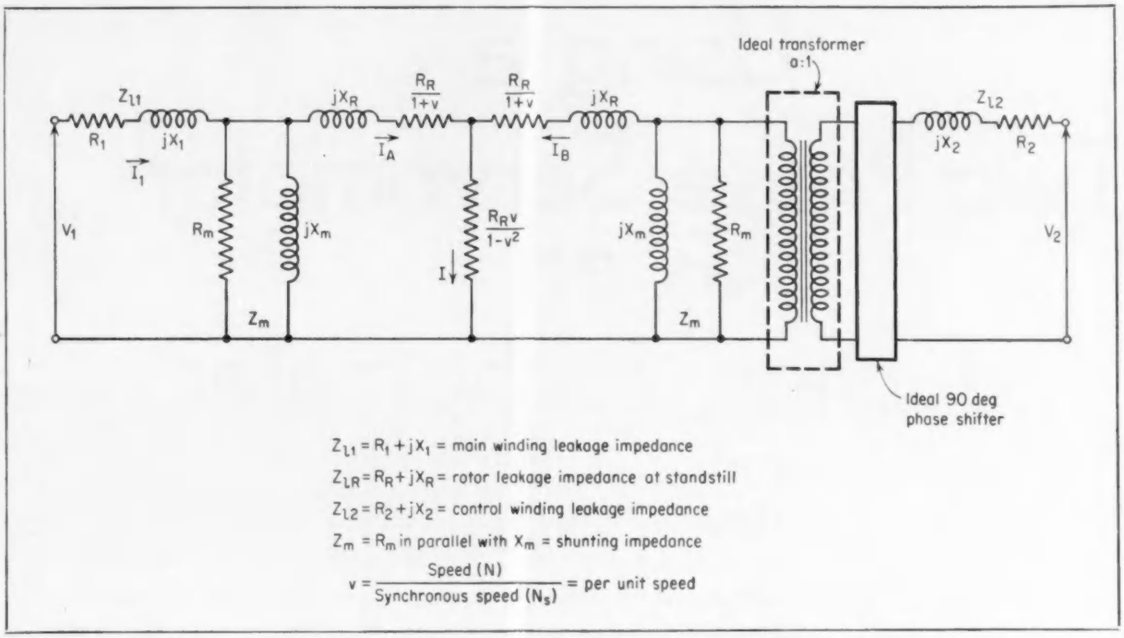
$$T = \frac{2{,}704}{N_s} R_R I_A I_B \cos\theta\,{}^{I_A}_{I_B} \quad \text{oz-in.} \qquad (4)$$

where all currents are expressed as magnitudes.

For the condition of balanced two-phase operation, V_2 equals minus jV_1. Therefore,

$$I_A = I_B = I_R$$

$$\cos\theta\,{}^{I_A}_{I_B} = 1$$



Equivalent circuit of two-phase induction machine

and Equation 4 reduces to

$$T = \frac{2{,}704}{N_s} I_R^2 R_R \tag{5}$$

Now expressing I_R in terms of the circuit impedances and I_1,

$$I_R = I_1 \left| \frac{Z_m}{Z_{lR} + Z_m} \right| \tag{6}$$

and substituting Equation 6 in Equation 5

$$T = \frac{2{,}704}{N_s} I_1^2 \left| \frac{Z_m}{Z_{lR} + Z_m} \right|^2 R_R \tag{7}$$

If the voltage source V_2 is disconnected from the machine, the voltage across the winding terminals is a measure of speed. This voltage can be determined from the equivalent circuit by direct calculation. Remember v is much less than one; then

$$| V_2 | = I_A R_R v \left| \frac{Z_m}{Z_{lR} + Z_m} \right| = \text{tachometer voltage at low speed} \tag{8}$$

I_A equals I_R at low speeds. Therefore, combine Equations 6 and 8:

$$| V_2 | = I_1 R_R v \left| \frac{Z_m}{Z_{lR} + Z_m} \right|^2 \tag{9}$$

Solving torque Equation 7 for R_R and substituting in Equation 9,

$$V_2 = \frac{v N_s T}{2{,}704 I_1} \tag{10}$$

And since v equals N/N_s,

$$V_2 = \frac{NT}{2{,}704 I_1} \tag{11}$$

To express this relationship in more common parameters, let $V_1 I_1 Pf$ equal the stall input watts, W, in the primary phase (where Pf is the power factor). Thus

$$I_1 = \frac{W}{V_1 Pf} \tag{12}$$

Substituting this in Equation 11,

$$V_2 = \frac{NTV_1 Pf}{2{,}704 W}$$

Thus, the final relationship expressing tachometer gradient as a function of motor torque per watt is

$$\left| \frac{V_2}{N} \right| = \frac{V_1 Pf}{1352a} \left(\frac{T}{2W} \right) \tag{13}$$

where V_2 = output volts
V_2/N = tachometer gradient = volts output per rpm
a = primary turns/secondary turns
= primary volts/secondary volts when the windings are rated at equal power per phase, W
Pf = power factor at stall
T = stall torque

HERE'S AN EXAMPLE

This relationship can be used to determine the tachometer gradient of a Bureau of Ordnance Mark VIII servomotor. Motor specifications are

W = 9.2 watts/phase
T = 2.35 oz-in.
Pf = 0.43
V_1 = 115 v
a = 1

$$V_2 = \frac{(115)(2.35)(0.43)}{(2704)(9.2)(1)}$$

$$\frac{V_2}{N} = 0.00396 \text{ v/rpm}$$

Automatic Machining— A View and a Preview

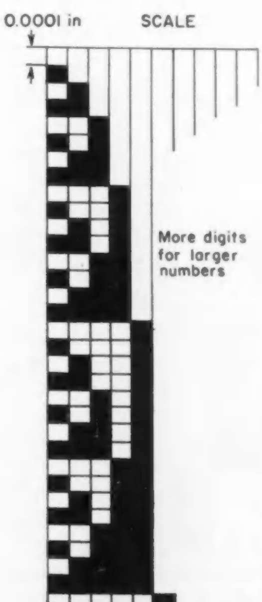
PART III: WAYS TO MEASURE POSITION AND SIZE

WALDO H. KLIEVER, Clevite-Brush Development Co.

The previous articles discussed ways to program, ways to actuate, and analog ways to measure. In this final article, Dr. Kliever covers digital position sensing techniques and ways to measure workpiece size.

DIGITAL WAYS TO MEASURE POSITION

With the high accuracy requirements of machine tools, digital techniques for measuring position are being investigated where discrete increments on a scale are read by photoelectric, magnetic, resistive, or capacitive methods. These devices have the advantages of designed-in accuracy, high speed (depending on associated electronic circuitry), and negligible reaction force on the carriage. In particular, it appears that digital measuring techniques will be well suited to the record-playback and numerical type director systems since the computing and recording can be restricted to the digital form. Digital records are more compact and can be reproduced with high accuracy.



BINARY VALUE	DECIMAL VALUE	DISTANCE, in.
00000	0	0.0000
10000	1	0.0001
01000	2	0.0002
11000	3	0.0003
00100	4	0.0004
10100	5	0.0005
01100	6	0.0006
11100	7	0.0007
00010	8	0.0008
10010	9	0.0009
01010	10	0.0010
11010	11	0.0011
00110	12	0.0012
10110	13	0.0013
01110	14	0.0014
11110	15	0.0015
00001	16	0.0016
10001	17	0.0017
01001	18	0.0018
11001	19	0.0019
00101	20	0.0020
10101	21	0.0021
01101	22	0.0022
11101	23	0.0023
00011	24	0.0024
10011	25	0.0025
01011	26	0.0026
11011	27	0.0027
00111	28	0.0028
10111	29	0.0029
01111	30	0.0030
11111	31	0.0031
000001	32	0.0032
100001	33	0.0033
010001	34	0.0034

FIG. 1. Digital positioning scale. Use of five binary digits gives 32 separately identifiable positions. A system like this needs accurately aligned detectors.

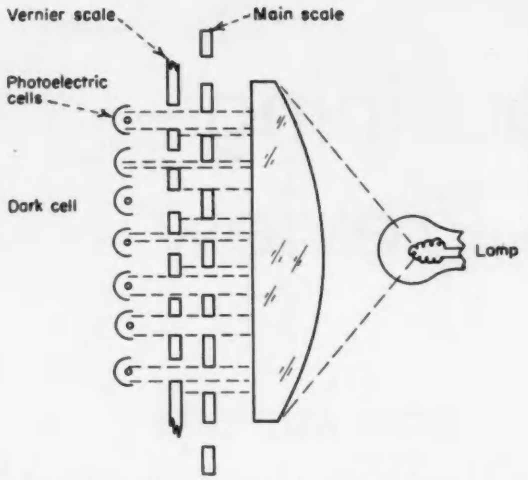


FIG. 2. Vernier type device for increased reading accuracy of binary scale. Main scale is read as shown in Figure 1. To this reading is added a number depending on the coincidence of the vernier.

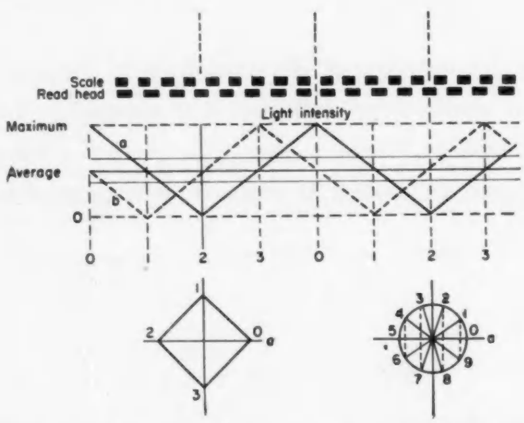


FIG. 3. Differential vernier that can read multiple lines with one photo-cell.

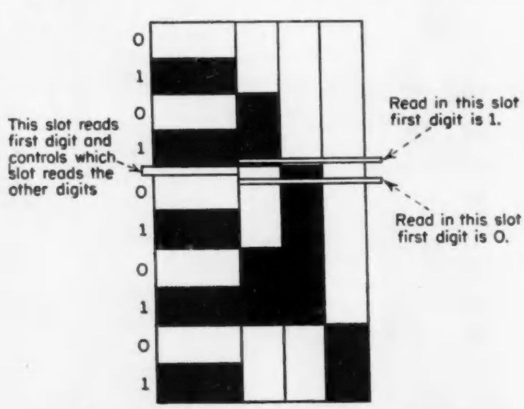


FIG. 4. Method of obtaining simultaneous change when a new number is called for. Switching operation by first digit selects point at which other digits are read.

Figure 1 shows a five-digit binary scale. If the fine divisions are 0.0001 in. thick, then the distance along the scale in inches is listed in the column on the right. With 20 binary digits this system can provide one million separately identifiable positions for a total range of 100 in. Then if the binary identifying marks are 0.1 in. wide, the scale for 20 digits is 2 in. wide.

There are two problems associated with this scale. It is difficult to identify a line that is only 0.0001 in. thick. And the pickup device must be aligned to closer than 0.0001 in. across the total width of the scale (1 to 2 in.). To get around this it is possible to use a vernier together with coarser divisions on the main scale. Then even with the thicker lines the scale system will still read to 0.0001 in.

A photoelectric system using this principle is shown in Figure 2. Since the divisions are still closer together than photocells can be placed, it is necessary to use diffusing or deflecting devices for the beams and to focus the respective spots on the cells. Also since the system must distinguish the coincidence from the other conditions, it is necessary to look at all the lines of the vernier. This means that individual devices must be used for sensing each line, or scanned in sequence at high speed.

A differential vernier can also be used to read multiple lines with one photocell, providing advantages of more light and less dependence on perfection of each line. Line a and the corresponding shaded pattern of Figure 3 show how light intensity in such a system varies with a linear sawtooth pattern, giving rise to Moire fringes. Reading at a point ¼ cycle of intensity away from a produces an intensity curve b. The diagram at the lower left plots a and b in a phase plane. If the slits through which a and b are read are made ¼ cycle wide and adjacent, the corners are rounded as in the right diagram. This is a fair approximation to a circle, and can serve as a zero switch for coarser scales or can be subdivided by comparison with a resolver so that readings to 0.0001 in. can be obtained with an 0.001 in. scale.

The other problem that occurs in all digital conversions is insuring that when changing from one number to another, all the digits that need to change do so exactly at the same time. Otherwise a false reading would disturb the servo system.

One solution to this problem is shown in Figure 4. In principle, it requires that every digit, except the first one, be viewed at two points, say at one-quarter of the fine digit thickness on either side of the first digit reading slot. The diagram shows a means of switching so that the system has a choice of which of the two reading points is used in a reading. This choice is made by the reading device on the first digit and is changed at the point where the reading device crosses the dividing line between digits. This results in the simultaneous change of all digits and prevents ambiguity.

The techniques described above use a simple or

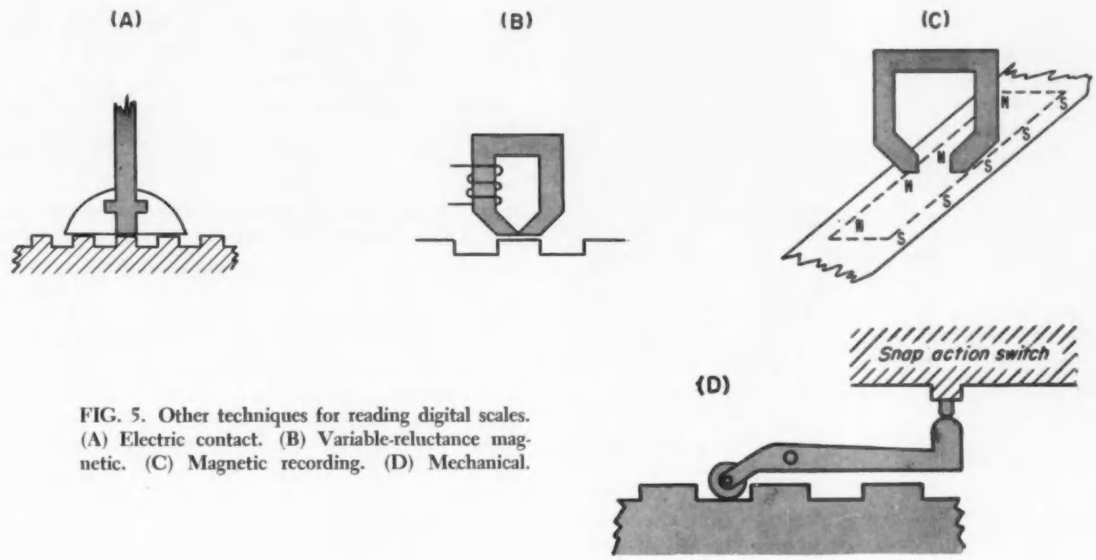


FIG. 5. Other techniques for reading digital scales. (A) Electric contact. (B) Variable-reluctance magnetic. (C) Magnetic recording. (D) Mechanical.

normal binary code. However, decimal, binary decimal or other codes might be used instead. The reflected (or progressive, cyclic, gray) code offers advantages from the standpoint of reducing the effect of error in reading, since only one digit changes at a time, eliminating the ambiguity at crossover. But this requires conversion before comparisons or computations are made.

The simplest type of digital scale involves a single series of lines or dots that are counted with a fast electronic counter as the reading device moves over the scale. It would necessarily need to subtract as well as add to determine position. But one disadvantage of this system is that if it makes a mistake, such as omitting to count one unit, that error is carried forward in every subsequent reading. The two-phase system described above gives information about direction of motion, thereby reducing the probability of such errors.

Another system uses a small number of digits which define a period long enough so that the loss of a complete period is very unlikely. The scales described above identify each position uniquely over the full range.

The use of a single track counting scale with an additional scale or other device that can check and correct the accuracy of the count at longer intervals offers an alternative solution. This system, which periodically eliminates accumulated errors, generally can operate with simpler reading facilities than a completely unique scale. For example, assume that for every thousand units of the counter scale there is a uniquely defined point. Then every time the reading head passes one of these points, the number on the counter is checked to see if it reads an even thousand. If the last three digits read 999 or 001 the necessary correction is made, since it can be assumed that the system is operating properly with an error of only one unit of the counter scale.

In addition to the optical and photoelectric reading techniques discussed above there are other ways of obtaining information from a digital scale. These include electrical contact, variable-reluctance magnetic, magnetic recording, mechanical, and capacitive. While they can use the same types of coding listed above, the manner of recording the information on the scale and of reading this information is different. In general these additional techniques will not give the resolution of the optical method.

Figure 5A shows a commutator type scale with electrical contacts. The contacts must be flexible to insure contact with multiple binary digits, and will need a shoe of nonconducting material to carry it over the open sections if the openings in the scale are not filled. Although wear problems are encountered, this method has been successfully used in many commercially available analog-to-digital converters.

A scale that can be read with a variable-reluctance magnetic head is shown in Figure 5B. The presence or absence of the raised surface changes the inductance of the coil. Since this type head depends on the airgap for its reading, this gap must be maintained constant. If there is a question of the airgap varying, the magnetic head can be mounted in a shoe as shown in Figure 5A.

In the magnetic recording method, the binary digits are indicated by magnetized areas on a magnetic material, Figure 5C. For example, a magnetic coating material, such as used on magnetic recording drums, can be sprayed or plated directly on the machine bed. Since it is necessary to know carriage position even when it is not moving, flux or static type magnetic heads must be used. These operate in a similar manner to a saturable reactor

in that the flux introduced by the magnetic recording changes the permeability of the iron core.

Some of the binary digits are very large and a magnetic field must be impressed along the entire width of the digit. Thus magnetizing at right angles to the direction of travel is better than the longitudinal recording techniques commonly used in magnetic recording machines. Although constant airgap is not too important, under certain conditions it may be desirable to mount the reading head in a shoe.

A simple system uses mechanical feelers (rollers or levers) to sense the high and low spots corresponding to the binary digits on a scale. In Figure 5D a microswitch converts this change in position into an electrical signal. The disadvantages of this method are excessive wear and limited resolution.

If a condenser plate is mounted similar to the electrical contact in Figure 5A and made one leg of a high frequency bridge, the proximity of high and low areas can be detected from the change in capacity. Theoretically this could be a noncontacting system. But in practice, it is difficult to maintain the airgap with sufficient accuracy if the digits are close enough together to give the necessary resolution.

In general the aforementioned reading heads require some control of the spacing to the scale. One attractive technique for doing this floats the head on a compressed air film. This also has advantages for removing dirt.

With all of these digital scale techniques, the scale reading is the signal indicating actual position of the carriage. As in the analog systems, this signal must be compared with one representing desired position and the difference used to bring the two into correspondence.

Most of these digital scales can also be constructed in a circular shape for use with rotary carriages or screws.

WAYS TO GAGE SIZE AUTOMATICALLY

The previous section assumed that the precise control of carriage position would in turn mean the precise control of workpiece dimensions. But this is not always true, since such things as tool wear, flexure of the work, tool or machine, thermal expansion, and variations in material properties can effect workpiece size even if the carriage is properly positioned. While this can be corrected by a sampling inspection of the finished pieces, a better way is to continuously gage and control workpiece size during machining.

This is not a simple problem. Interference between the tool and gage, variations in workpiece shapes, gage wear, dirt, chips and coolant all make it difficult to design and operate a successful system. For this reason, attempts at automatic gaging have been primarily applied to grinding operations. Grinding involves a cylindrical or flat surface and is a relatively clean operation.

Both contact and noncontact gages can be used. The contacting types include direct mechanical and electrical sensing, while the noncontact types include pneumatic, variable capacitance, optical, and magnetic inductance. Direct mechanical and electrical sensing and pneumatic gages have been successfully applied.

The direct mechanical type consists of a follower immediately behind the cutting tool that decides when sufficient metal has been removed by comparing with a value pre-set into the gage or called for by an electrical signal from a memory device. This method has been successfully used on a grinder as shown in Figure 6. In this machine a caliper rides the work and continually controls the infeed of the grinding wheel to maintain the desired-size accuracy within plus or minus 0.0005 in.

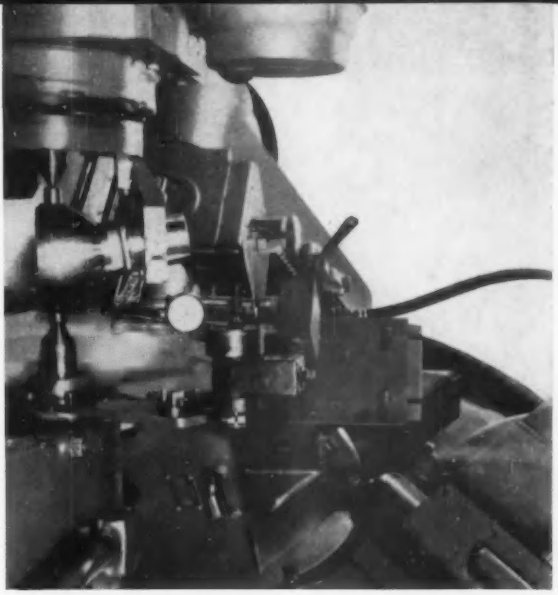
A crankshaft grinder that uses a diameter-to-electrical signal transducer to continually gage main bearing diameter is shown in Figure 7. In this unit the steady rest automatically moves in to support the particular journal being ground, and then the grinding wheel reduces crank diameter to a size that is pre-set into the control system. During the roughing portion the infeed is fast, but slows down as the desired diameter is approached. If the bearing is being ground out-of-round, as a result of improper crank alignment in the machine, the wheel is retracted and the condition indicated to the operator. This system might be expected to grind within plus or minus 0.0005 in. With automatic loading and unloading equipment, it could handle the complete grinding operation automatically.

Probably the pneumatic gage is the most useful. It does not touch the workpiece so that there is no wear problem, and the air has a tendency to blow the dirt away from the gaged surface. The pneumatic gage indicates size by the amount of air leakage between the gage and the work, at constant pressure. A possible variation measures the change in pressure at constant flow. The pneumatic signal can be converted to a proportional electrical signal which is compared with a signal indicating desired size.

Where it is impossible to use continuous automatic gaging, it may be possible to gage the workpiece immediately after it leaves the machine and then reset the carriage. This technique has been applied to both lathes and grinders.

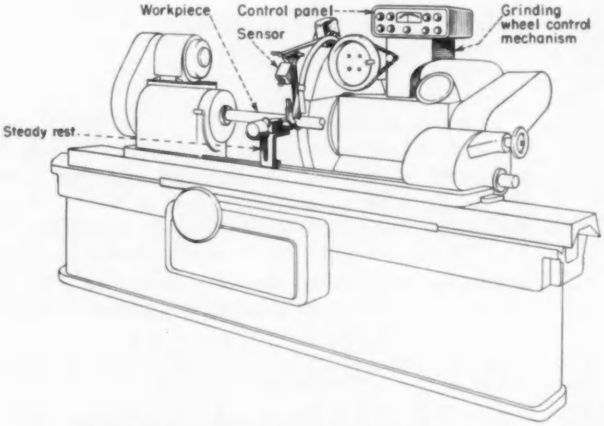
Figure 8 shows a typical system. The grinder is producing cylindrical slugs with accurately machined ends. As each slug leaves the grinder it is gaged pneumatically and the measurement converted to an electrical signal. If the piece is within a reset-tolerance band nothing happens and it leaves via the acceptable-pieces chute. If a piece is outside the reset-tolerance band, but still within an acceptance tolerance, it still leaves via the acceptable chute, and

AUTOMATIC GAGING APPLIED . . .



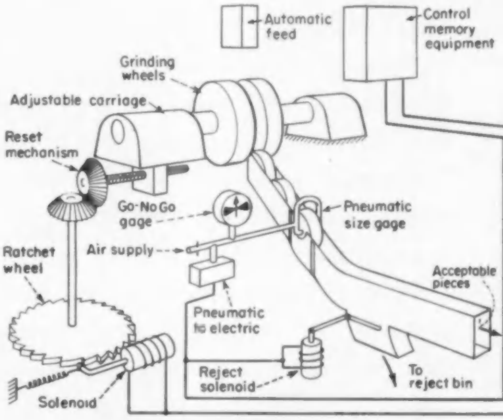
. . . BY MECHANICAL CALIPER

FIG. 6. Grinder with continuous automatic gaging. Mechanical caliper measures work size and controls grinding wheel infeed. Cincinnati Milling Machine Co.



. . . BY ELECTRICAL TRANSDUCER

FIG. 7. Crankshaft grinder with diameter-to-electrical signal transducer to continuously gage and control bearing size.



. . . BY PNEUMATIC MEANS

FIG. 8. Reset gaging. Workpiece is gaged pneumatically after it leaves grinding wheels. If pieces are oversize, adjustable carriage is driven in to compensate for wheel wear.

the information is recorded in the memory counter as "one piece outside the reset tolerance but still acceptable". When the machine puts out three pieces like this in a row, the control unit energizes the ratchet wheel solenoid and the adjustable carriage is moved in a fixed amount to compensate for wheel wear. The number of pieces required to cause reset is adjustable since it is possible for the machine to produce one or two pieces outside the reset-tolerance band and then continue producing good pieces. Reset is not required in this case, and once a good piece is produced the counter is returned to zero.

A piece that is out of the acceptance tolerance range is immediately rejected to the reject bin. This information is also stored in a separate counter memory. A fixed number of these rejects in a row (where intermediate adjustment of the carriage does not correct the condition) indicates that something is wrong with the machine and it shuts down.

Where machine operation is programmed to control carriage position, a signal indicating the error in the finished piece could be added to the signal called for by the memory device or, in some cases, the correction could made in the recorded memory itself. This can be done with magnetic type memories that can be erased.

It is possible that the gaging device could be an entirely separate inspection machine that looks at a piece after it is completed and removed from the production machine. The correction could then be applied automatically at a convenient later time. It might even use statistical sampling and averaging techniques instead of looking at every unit.

Digital Computers Need

Orderly Number Systems

THE GIST: Numbers are symbols that represent information. Only a few of the various ways for writing numbers lend themselves to machine methods. Computer solution of problems demands simplified mechanisms and orderliness of numerical systems.

This article deals with number systems, a necessary preliminary to detailed study of digital computer operation. Systems of counting and formation of numbers, presented herein, frame basic arithmetic operations—addition, subtraction, multiplication, and division—in the decimal, binary, and octal systems.

Against this background are introduced several methods of coding decimal digits in binary form. These methods simplify computer mechanism and give results compatible with our everyday decimal system. Inherent in one of these codes is a check against computer malfunction; the others need the addition of a checking digit.

IRWIN S. LERNER, Royal McBee Corp.

Numbers indicate quantity, information, and physical objects, and specify order. In a computer composed of physical devices, the *state* of these devices describes a particular number. When these devices are arranged to mutually affect each other in some predetermined and orderly manner, this arrangement facilitates desired and orderly manipulation for solution of numerical problems. What is a methodical way to specify the idea of quantity? That is, what system of numbers allows for easy manipulation of arithmetic operations?

One possibility is that of the *mark*, wherein representation of the quantity x requires x similar marks. This can be called the *tally* system. One needs little memory to retain the meaning of a single *mark*, but much space to specify a fairly large number of marks. Also, grasping the numerical significance of a large *tally* becomes difficult. At the other extreme of number language, however, a separate symbol, which requires *mutual agreement* as to meaning, identifies each idea of number. Thus, to specify a particular quantity requires very little space, but one needs an inexhaustible memory to retain the infinite number of symbols representing the infinite ideas of quantity.

Between these two extremes lies the *mark-position* system. The decimal system, in everyday use, is an example of this scheme. Here, only ten different *marks* need be remembered, with the idea of number consisting of these *marks* and their *position* in the number. Not only is the *mark-position* system within the range of human ability, but its logical arrangement fits in with the design of practical digital computers. Other *mark-position* systems in common usage for computers include *binary* and *octal*. Each of the systems has a different number of *admissible marks* (digits):

SYSTEM	ADMISSIBLE MARKS	RADIX
Decimal	*0, 1, 2, 3, 4, 5, 6, 7, 8,* and *9*	10
Binary	*0* and *1*	2
Octal	*0, 1, 2, 3, 4, 5, 6,* and *7*	8

Counting

We all count and do other arithmetic operations with facility in the decimal system because of long years of association with this method. These operations depend on certain rules that also apply to other *mark-position* number systems. Since it may be difficult to translate the process of counting in the decimal system into any other system, here is a good spot to review the basic rules for counting:

► Starting from a position at the right, the number has an unlimited sequence of positions to the left.

► In each position the mark *0*, meaning *nothing,* and one or more other marks are admissible.

► To obtain the number one greater than a given number, raise the extreme right-hand mark to the next higher admissible mark. If this is already the highest admissible mark, go left to the first position where the mark is not the highest one possible, raise this mark to the next mark, and set everything at the right to *0*. This is known as carry.

The Pattern of Numbers

These rules and the following formula pattern the formation of numbers:

$$N = A_n r^n \ldots A_2 r^2 + A_1 r^1 + A_0 r^0 + A_{-1} r^{-1} + A_{-2} r^{-2} + \ldots A_{-n} r^{-n}$$

where N is the number

A is an admissible mark.

r is the radix (the total number of admissible marks in the system).

n is the position of the mark ($n = 0$ is in the first position, with increasing values of *n* in positions starting from the left.)

The Decimal System

This formula may seem formidable, but witness the formation of the number *4999* in the decimal system and note the pattern:

$$4999 \text{ equals } 4000 + 900 + 90 + 9 \text{ or}$$
$$4 \times 1000 + 9 \times 100 + 9 \times 10 + 9 \times 1 \text{ or}$$
$$4 \times 10^3 + 9 \times 10^2 + 9 \times 10^1 + 9 \times 10^0$$

Here $n = 3$, $A_3 = 4$, $A_2 = 9$, $A_1 = 9$, $A_0 = 9$, and all other A's $= 0$.

Thus numbers are formed by stating the coefficients (mark) of the powers (position). They develop similarly in systems using other radices.

The Binary System

The binary system contains two admissible marks, *0* and *1*, and therefore the radix is two. For example, the number N represented by the binary notation *11010* is:

$$N = 1 \times 2^4 + 1 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 0 \times 2^0$$
$$= 1 \times 16 + 1 \times 8 + 0 \times 4 + 1 \times 2 + 0 \times 1$$
$$= 16 + 8 + 2 = 26 \text{ (decimal equivalent)}$$

BINARY

MULTIPLICAND \ MULTIPLIER (PRODUCT)	0	1
0	0	0
1	0	1

OCTAL

MULTIPLICAND \ MULTIPLIER (PRODUCT)	0	1	2	3	4	5	6	7
0	0	0	0	0	0	0	0	0
1	0	1	2	3	4	5	6	7
2	0	2	4	6	10	12	14	16
3	0	3	6	11	14	17	22	25
4	0	4	10	14	20	24	30	34
5	0	5	12	17	24	31	36	43
6	0	6	14	22	30	36	44	52
7	0	7	16	25	34	43	52	61

FIG. 1. Number equivalents for several single-radix systems shows methodical number pattern and operation to carry.

DECIMAL	BINARY	TERNARY	OCTAL
0	0	0	0
1	1	1	1
2	10	2	2
3	11	10	3
4	100	11	4
5	101	12	5
6	110	20	6
7	111	21	7
8	1000	22	10
9	1001	100	11
10	1010	101	12
11	1011	102	13
12	1100	110	14
13	1101	111	15
14	1110	112	16
15	1111	120	17
16	10000	121	20
17	10001	122	21
18	10010	200	22
19	10011	201	23
20	10100	202	24

FIG. 2. Addition tables for the binary and octal systems can be arranged like the more common decimal addition table.

To raise *11010* (binary) to the next number greater, raise the extreme right-hand mark *(0)* to the next highest admissible mark *(1)*, raise the result, *11011*, to the next number greater by moving left to the first mark that is not the highest possible *(0)* in third position), raise this to the next higher mark *(1)*, and set everything at the right to *0*. Therefore, the next number greater than *11011* becomes *11100*.

The Octal System

The octal system contains the admissible marks *0, 1, 2, 3, 4, 5, 6,* and *7*; therefore the radix is eight. Applying the number *356* (octal) to the formula to find the equivalent decimal number results in:

$$N = 3 \times 8^2 + 5 \times 8^1 + 6 \times 8^0$$
$$= 3 \times 64 + 5 \times 8 + 6 \times 1$$
$$192 + 40 + 6 = 238 \text{ (decimal)}$$

Number equivalents up to *20* (decimal) comprise Figure 1; this figure also contains equivalents in the *ternary* (radix 3) system, which has not been discussed but may be of interest. Note the process of carry in each system as the numbers increase.

ARITHMETIC OPERATIONS

Arithmetic expresses in a numerical language the logical pattern of meaning that leads to conclusions. An examination of basic arithmetic operations suggests possible alternative methods of performing these operations and permits selection of those methods most suitable for machine manipulation.

Addition

Addition successively raises a number to the next number greater a given number of times. Speed is achieved through memorization by the individual of the decimal addition table. In performing addition one thinks of the addend and augend and reads the sum from his memory.

Addition tables can be arranged for any *mark-position* number system; those for the *binary* and *octal* systems are shown in Figure 2. Here is an example of how two quantities (26 and 58) can be added in the *decimal, binary,* and *octal* systems:

DECIMAL	BINARY	OCTAL
26	11010	32
58	111010	72
84	1010100	124

Binary addition of two numbers is quite simple. However, the addition of more than two numbers complicates the manner of making the carry to the next column at the left. For a fairly long series of numbers, the carry (resulting from adding a column) may extend *more than one* column to the left. Witness the difficulty in trying to handle the carry when adding these binary numbers:

```
   11010
  111010
  101011
   10010
   11001
--------
10101010
```

A better way to sum these numbers: add the first number to the second; take this sum and add it to the third number; take this next sum and add it to the fourth number; and so on to the end of the series. This procedure permits the use of a simplified mechanism whose speed compensates for the additional operations.

Subtraction

Subtraction is the reverse of addition. It reduces a number to the next lower number a stated number of times. In machine calculating, subtraction is more difficult than addition because a physical process must be reversed if the calculation is to be performed in a straightforward manner. Many of the devices used in machine calculation cannot be reversed easily, if at all. Although a toothed wheel reverses easily for the subtraction process, its drawback is that if subtraction goes far enough to give a negative number the indicated numbers continue to decrease. Actually, they should suddenly begin to increase on the minus side.

The *complement* method facilitates subtraction, providing the correct sign as well as sudden increase from zero. If a number C (the complement) can be found and *added* to a given number A, it will give the same result as *subtracting* the number B from A. Here, C is the *complement* of B. In the decimal system two complementing methods exist: the *10's complement* and the *9's complement*.

The *10's complement* forms by subtracting the number B from 10^n, where n is the number of digits available on the machine. For example, to subtract *426* from *782* in a four digit machine, the steps are as follows:

> The *complement* of *426* is *10000–426=9574*.
> Adding *9574* to *782* yields *10356*.
> The *1* in the fifth position does not appear (there being only four positions in the machine), so the result is *356*, which is correct.

Machine difficulty arises in forming the *10's complement* because all corresponding digits of the original number must subtract from 9, except for the farthest right hand non-zero digit, which must subtract from *10*. This difficulty is overcome by resorting to the *9's complement*.

The *9's complement* forms by subtracting the number from 10^n*–1* (*9999* if *n* equals *4*) rather than from 10^n. Thus, each digit of the number is subtracted from 9, and the machine does not have to distinguish any special operations. Using the *9's complement* in the preceding example:

BINARY

	MULTIPLIER 0	MULTIPLIER 1
	PRODUCT	
MULTIPLICAND 0	0	0
MULTIPLICAND 1	0	1

OCTAL

MULTIPLICAND \ MULTIPLIER (PRODUCT)	0	1	2	3	4	5	6	7
0	0	0	0	0	0	0	0	0
1	0	1	2	3	4	5	6	7
2	0	2	4	6	10	12	14	16
3	0	3	6	11	14	17	22	25
4	0	4	10	14	20	24	30	34
5	0	5	12	17	24	31	36	43
6	0	6	14	22	30	36	44	52
7	0	7	16	25	34	43	52	61

FIG. 3. Multiplication tables in the binary and octal systems show similarity to the arrangement used in the decimal system.

The complement of *426* is *9999—426=9573*.
Adding *9573* to *782* gives *10355*.
Here the *1* in the fifth position does not appear but is carried (end-around carry) to the first position and added to *0355*, yielding *356*, which is correct.

The *9's complement* requires one place to the left for a sign indicator. If the digit in this position is *0*, the numbers following are positive; if *9*, they are the complement of a negative number.

Binary subtraction follows the same rules, but with more convenience. When using complements, it is necessary only to change all *0's* to *1's* and all *1's* to *0's*. Machine methods accomplish this change easily. *Binary* subtraction, with and without complements, is shown in the following example—with decimal equivalents:

WITHOUT COMPLEMENTS

Decimal	Binary
57	111001
23	10111
34	100010

WITH COMPLEMENTS

Decimal	Binary
057	111001
976	101000
1033	1100001
→1	→1
034	100010

Octal substraction occurs in a similar way. The inverse of addition or *7's complements* can be used.

WITHOUT COMPLEMENTS

Decimal	Octal
57	71
23	27
34	42

WITH COMPLEMENTS

Decimal	Octal
057	071
976	750
1033	1041
→1	→1
034	042

Multiplication

Mutiplication successively adds the same number a given number of times. But in practice successive additions usually give way to memory (multiplication table) to obtain the product of two numbers. Multiplication tables for the *binary* and *octal* systems are shown in Figure 3.

The rules for multiplying can be observed by the way they work in the decimal system; here *219* is to be multiplied by *45*:

219	219		219
4	5		45
36	45	or	1095
4	5		876
8	10		9855
876	1095		
1095			
876			
9855			

The multiplication process in any single radix consists of a routine of continually changing steps:

1. Select multiplicand digit
2. Select multiplier digit
3. Refer to the appropriate multiplication table
4. Obtain the value of the product
5. Add the preceding carry
6. Set down the right-hand digit in a position related to the position of the multiplier digit
7. Carry the left-hand digit.
8. Repeat steps 1 to 7 until all multiplications have been performed
9. Add the digits set down

The sixth step involves the operation of *shift*, by which the significance of the position of a mark in a written number is maintained. In machine calculation, provision must be made for automatic shifting to obtain the proper number of positions for summing partial products.

Two mathematical tricks can simplify a machine structure for multiplying: the first is multiplication by components. This eliminates the conventional carry procedure, but sets down the carries separately and adds them separately. Note in this sample decimal calculation how summing the right- and left-hand components requires an extra step:

$$\begin{array}{rrr}
\text{Right-Hand Digits (mark)} & & \text{Left-Hand Digits (carry)} \\
219 & & 219 \\
45 & & 45 \\
\hline
055 & & 104 \\
846 & & 003 \\
\hline
8515 & 8515 \text{ (Right-Hand)} & 134 \\
 & 134 \text{ (Left-Hand)} & \\
\cline{2-2}
 & 9855 \text{ (Sum)} &
\end{array}$$

The second method changes the digits in the multiplier to digits between *0* and *5*, with a sign (positive or negative) attached. This reduces the number of parts in a machine. For example, a decimal multiplicand with ten marks and a multiplier with six marks and a sign facilitates the machine solution of *219* multiplied by *89*:

The number *89* can be expressed as *100–10–1*, or $1\bar{1}\bar{1}$, where a bar indicates a negative digit.

$$\begin{array}{rcr}
219 & \qquad & 219 \\
1\bar{1}\bar{1} & & 89 \\
\hline
-219 & & 1971 \\
-219 & & 1752 \\
219 & & \\
\hline
19491 & & 19491
\end{array}$$

Binary multiplication is quite simple since the highest multiplier mark is *1*. The process reduces to repetitive addition with appropriate shifts to the left. When multiplying two *binary* numbers simply write the multiplicand if the multiplier is a *1*, and do not write it (but allow for one shift to the left) if the multiplier digit is a *0*. Proceed in this manner until all partial products of the multiplicand and all the digits have been written. Most difficult is the *binary* addition of the partial products.

$$\begin{array}{r}
11010 \\
10011 \\
\hline
11010 \\
11010 \\
11010 \\
\hline
111101110
\end{array}$$

Octal multiplication involves the same logical approach, the major difference being reference to the *octal* multiplication table. The following sample problem shows *octal* multiplications:

$$\begin{array}{rcrcrcr}
326 & \quad & 326 & \quad & 2056 & \quad & 326 \\
3 & & 5 & & 1202 & & 35 \\
\hline
22 & & 36 & & 14076 & & 2056 \\
6 & & 12 & & & & 1202 \\
11 & & 17 & & & & \\
\hline
1202 & & 2056 & & & & 14076
\end{array}$$

The decimal equivalent of this problem is:

$$\begin{array}{rcl}
214 & \qquad & \text{check 14076 according to the formula:} \\
29 & & \\
\hline
1926 & & 6 \times 8^0 = 6 \times 1 \quad = \quad 6 \\
428 & & 7 \times 8^1 = 7 \times 8 \quad = \quad 56 \\
 & & 0 \times 8^2 = 0 \times 64 \quad = \quad 0 \\
\hline
6206 & & 4 \times 8^3 = 4 \times 512 \quad = 2048 \\
 & & 1 \times 8^4 = 1 \times 4096 = 4096 \\
 & & \hline
 & & 6206 \text{ (check)}
\end{array}$$

Division

Division reverses the process of multiplication; that is, it consists of repeated subtraction or determining the number of times (the quotient) the divisor can be subtracted from the dividend. An example is division in the decimal system:

$$\begin{array}{rl}
13 & \\
25/328 & \\
-25 & \text{———— } 1 \\
\hline
78 & \\
-25 & \text{———— } 1 \\
\hline
53 & \\
-25 & \text{———— } 1 \\
\hline
28 & \\
-25 & \text{———— } 1 \\
\hline
3/25 & \quad 13
\end{array}$$

Note that subtraction continues without shift until a negative remainder results; at this point the appropriate shift occurs to the proper position.

In the *binary* system, division proceeds in a similar manner:

$$\begin{array}{r}
1101 \\
11001/\overline{101001000} \\
11001 \\
\hline
100000 \\
11011 \\
\hline
00011100 \\
11001 \\
\hline
11/11001
\end{array}$$

Of course, the *octal* system (or any other single radix system) follows the same steps for division of one number by another.

The quotient of two numbers in most cases will not be an integral number. The *radical point* separates the integral number from the remainder; in the decimal system the radical point is called the *decimal point*. Referring to the formula for forming numbers, it will be seen that numbers to the right of the *radical point* develop as increasing negative powers progressing to the right: in the *binary* system they are powers of $\frac{1}{2}$—$\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, etc.

One way of converting mixed *binary* numbers to the equivalent decimal value is to express the number as though there were no *radical point* and then divide by the radix raised to the number of occupied positions to the right of the point. For example:

$$\text{Binary} \qquad 11.0101 = \frac{2^5 + 2^4 + 2^2 + 2^0}{2^4}$$

$$= \frac{53}{16}$$

$$= 3.3125 \text{ decimal}$$

In machine operations the *radical point* can be located in a fixed way or changed for each problem put into the machine. For equipment having a fixed *radical point*, numbers must be *scaled* so that the largest number used is just smaller than the

BINARY NUMBERS	STRAIGHT BINARY CODED DECIMAL	7421 CODE	2* 421 CODE
0000	0000	0000	0000
0001	0001	0001	0001
0010	0010	0010	0010
0011	0011	0011	0011
0100	0100	0100	0100
0101	0101	0101	
0110	0110	0110	
0111	0111		
1000	1000	1000	
1001	1001	1001	
1010		1010	
1011			1011
1100			1100
1101			1101
1110			1110
1111			1111

FIG. 4. Several binary-coded decimal numbers aid conversion between decimal and binary notation, and economize on register length.

largest number that the machine will hold. This type of equipment is less complex than that of *floating radical* construction. In the *floating radical* machine, each operation influences the position of the *radical point*, until at the end of the complete calculation, the point occurs in the proper place. Although the mechanism is more complex, it relieves the operator of the necessity for rescaling the problem to find correct location of the *radical point*.

PHYSICAL CODING OF DIGITAL NUMBERS

All digital numbers can be encoded for machine handling; in encoding the state of a physical device must be changed to record the information. Most physical devices have two distinct states: some of these devices are punched tape (hole or no hole), magnetic tape (magnetized or not magnetized area), and relays (open or closed). Since these easily available states come in pairs, it is natural that the *binary* system play an important part in the coding and recording of digital numbers. Other advantages of the *binary* system include high operating speed, small space requirements, low manufacturing costs, and the economic feasibility of large-scale high-speed calculating machines.

Coded Numbers

Why, then, consider the use of any number system other than *binary* for high-speed machine calculating? Two reasons stand out: the widespread use of the decimal system in our daily lives, and the possibility of human error in dealing with long strings of digits containing only two different marks.

Binary-coded numbers aid conversion between the *binary* system and any other system. A binary-coded number expresses each digit of a number in any system by binary notation for each digit of that number. As an example, consider the decimal number *1024*, which can be written as:

Straight binary: 10000000000 or

Binary-coded decimal:	0001	0000	0010	0100
	(1)	(0)	(2)	(4)

Note that the straight binary representation of decimal *1024* requires eleven positions. Although the binary-coded decimal representation of the same number uses sixteen positions, its format is much easier to read. The sixteen positions in the binary code represent up to *9999* decimal numbers. This system offers coding methods that can be handled by machine calculators.

The most direct method of coding decimals in binary numbers uses the first ten sequential binary numbers, as the ten admissible marks in the coded decimal system (see Figure 4). This is a widely used procedure. The binary equivalent of the decimal digit *9* is *1001*, which means that each decimal digit requires four binary digit positions. As shown previously, this provides sixteen possible combinations, and since there are only ten admissible marks, six binary combinations are not used. There may be some advantage to using combinations other than the first ten binary numbers.

DECIMAL	EXCESS-THREE CODE
0	0011
1	0100
2	0101
3	0110
4	0111
5	1000
6	1001
7	1010
8	1011
9	1100

FIG. 5. The excess-three code used in binary representation of decimal numbers give a simplified process of carry.

5	0	4	3	2	1	0	DECIMAL
0	1	0	0	0	0	1	0
0	1	0	0	0	1	0	1
0	1	0	0	1	0	0	2
0	1	0	1	0	0	0	3
0	1	1	0	0	0	0	4
1	0	0	0	0	0	1	5
1	0	0	0	0	1	0	6
1	0	0	0	1	0	0	7
1	0	0	1	0	0	0	8
1	0	1	0	0	0	0	9

FIG. 6. Modern computers use the powerful self-check features of the biquinary-coded decimal system, tabulated above.

For instance, McBee Keysort equipment uses notches in the edge of a card to record information. Here it becomes desirable that no more than two notches (*1's*) be required to indicate a decimal digit. Therefore, of the sixteen available, the first ten binary numbers that have two or less *1's* digits make up the coded system known as the *7421* code (see Figure 4). The name of this code derives from the decimal value of the binary positions: going left from the radical point, the first *1's* digit has the decimal value of one, the second has the decimal value of two, the third the value of four; and the fourth the decimal value of seven (as compared with eight in the straight binary-coded decimal).

Another code uses the first five and last five of the sixteen four-digit *binary* numbers. With this arrangement the *9's complement* of a decimal number develops simply by changing all *1's* to *0's* and all *0's* to *1's* in the binary-coded representation. This code has the name *2*421* (Figure 4), again derived from the decimal value of the *binary* position.

When the binary-coded decimals mentioned above appear in machine calculations, some difficulty arises in making the carry. If two binary-coded decimals are added, the result may be one of the balance of the sixteen *binary* numbers not admissible in the code. For example, using the straight binary-coded decimal (Figure 4) the sum of eight and five would appear as the thirteenth (and inadmissible) *binary* combination, *0000 1101*. The desired result should be: *0001 0011*—*binary* three in the first position and *binary* one in the second position.

The excess-three code (Figure 5) facilitates correct *carry* when using binary-coded decimals. In this code, each decimal digit is represented by a *binary* number that is greater by three than the *binary* equivalent of the decimal digit. Thus, the *binary* sum of two decimal digits coded in this way is excessive by six. Subtraction of three converts this sum to an excess-three number.

However, when the sum of the two digits requires a decimal *carry* (as in the sum of 8 and 5), the binary-coded representation of the sum exceeds the four *binary* positions; that is, the sum now uses five *binary* positions. Since the arrangement of the code allows only four positions, the fifth position carries over into the *binary* representation of the second decimal position and three is added to the *binary* digits of the first decimal position. Here are two examples of addition using the excess-three code:

1)

	8	1011
	5	1000
CARRY		$1/\overline{0011}$

To return to excess-three code, add *binary* three (*0011*) in each position:

0100 0110 = 13.

And 2)

	4	0111
	3	0110
NO CARRY		$\_/\overline{1101}$

To return to excess-three code, add *binary* three (*0011*).

1010 = 7

A binary-coded *octal* number system economizes on equipment because it makes use of all combinations of three *binary* positions in representing the first eight *octal* numbers (see Figure 1). No *binary* combinations are wasted. Also, *octal* numbers approximate decimal numbers—thus, a computer operator can check results at least to order of magnitude. Several coding schemes, however, employ *self-checking* means.

Coding For Self-Checking

The key to self-checking depends on the representation of digits by devices such that the failure of any one device gives an *error* pattern. This pattern *does not represent* one of the admissible digits in the code used, and therefore can be made to stop the machine, actuate an alarm, or flash a light. In fact, with certain additional equipment, the system becomes self-correcting as well as self-checking.

The *biquinary-coded* decimal system (Figure 6) contains inherent self-checking. In this scheme, each digit can be represented by the position of a *binary* device. Note that the representation of a decimal digit requires exactly the actuation of two *binary* devices, one in each of two groups. Therefore, whenever any other distribution or number of *binary* devices operates (in any one decimal position) the machine detects a malfunction by a mechanism that continually looks at the number and position of *binary* devices operated.

The *biquinary* notation may be considered a mixed radix system. The value of the first position is units, that of the second, five, the third, ten, the fourth, fifty, and so on. In *biquinary* representation, *carries* are made on the basis of powers on ten, as

in the decimal system. The abacus, of Chinese origin, employs the *biquinary* scheme.

Any code that is not inherently self-checking can become self-checking with the addition of a *binary* checking digit to the coded representation of each decimal digit. The checking digit is so chosen that in error-free operation, the number of actuated *binary* elements for every decimal digit is odd (odd parity check) or even (even parity check) as desired. In the odd parity check, below, checking digits are shown for the *binary* (not binary coded) representation of several decimal numbers:

	NUMBER	CHECKING DIGIT
12	1100	1
13	1101	0
14	1110	0
15	1111	1

In the checking digit column, changing the *1's* to *0's* and the *0's* to *1's* gives even parity check.

A self-checking coded-decimal number system requires that at least five *binary* positions be assigned to each decimal digit. If all *binary* numbers up to a maximum of five positions are listed sequentially the last number of the series will be *11111 (binary)*. In this list there are exactly ten numbers that contain two, and only two, *binary 1's*. The assignment of a decimal digit equivalent to each of these numbers establishes a self-checking two out of five code. By proper arrangement of the list a weighted positional code is obtained. For example, the *01236* code (Figure 7) results in this way.

Another interesting self-checking device consists of the inclusion of a checking digit as part of a number. Given a number that requires a self-checking digit: proceeding from the left, add the value of the first digit to *twice* the value of the second digit; add this sum to the value of the third digit; add to *twice* the value of the fourth digit; add to the value of the fifth digit; and so on. The value of the unit's position in this checking sum is the checking digit. This digit is then appended to the number. For instance, according to this method, the number 54279 has the self-checking digit 8. Therefore, the self-checking number becomes 54279-8. This system readily indicates errors due to accidental transposition of digits in the number.

DECIMAL	0	1	2	3	6
0	0	1	1	0	0
1	1	1	0	0	0
2	1	0	1	0	0
3	1	0	0	1	0
4	0	1	0	1	0
5	0	0	1	1	0
6	1	0	0	0	1
7	0	1	0	0	1
8	0	0	1	0	1
9	0	0	0	1	1

FIG. 7. The 01236-coded decimal uses exactly two binary positions to represent a decimal number, and hence is inherently self-checking.

REFERENCES

1. *ARITHMETIC OPERATIONS IN DIGITAL COMPUTERS*, R. K. Richards, D. Van Nostrand Co., Inc., 1955.
2. *GIANT BRAINS*, E. C. Berkeley, John Wiles and Lass, Inc., 1949.
3. *HIGH-SPEED COMPUTING DEVICES*, Staff of Engineering Research Associates, Inc., McGraw-Hill Book Co., Inc., 1950.
4. *THE DESIGN OF SWITCHING CIRCUITS*, W. Keister, A. E. Ritchie, and S. H. Washburn, D. Van Nostrand Co., Inc., 1951.

IRWIN S. LERNER

Irwin Lerner is an Electrical Engineer by training and has concentrated on the design and application of electronic computers during most of his career. After earning his BS in EE from Oklahoma A. & M. College in 1948, he went to work designing geophysical exploration equipment for Continental Oil Co. In 1951 he joined Armour Research Foundation to head up its computer development program and while at the Foundation organized and taught courses in applying computers to business systems at Illinois Institute of Technology. Early this year Mr. Lerner went to Hartford to plan electronic computer research activities for Royal McBee Corp.

Color Basics for The Control Engineer

PART 2: THE INSTRUMENTS OF COLOR MEASUREMENT

In the October issue Mr. Olson analyzed color by means of an engineer's block diagram and reviewed the established means for drawing color curves and expressing color in numbers. In this concluding article he examines the specialized instruments for measuring color and gives some examples of their use in industry.

O. H. OLSON, Armour Research Foundation

Many photoelectric instruments to objectively evaluate color have been developed in recent years. Colorimeters, color analyzers, color comparators, tristimulus meters, color difference meters, spectrophotometers, and many others are typical of the names given to such instruments. Since it is not obvious from their names that these instruments do not all measure the same thing, a classification would seem desirable. The principal classes into which most color instruments fall are:

1. Spectrophotometers
2. Abridged spectrophotometers
3. Tristimulus colorimeters

A spectrophotometer uses a prism or grating to disperse light into a spectrum either before or after the light is incident upon the test sample. Slits in the instrument isolate a narrow band of wavelengths so that the reflectance or transmittance can be measured at each spectrum color. This is monochromatic measurement. Since the spectrum formed by a grating or prism is continuous, points on the color curve can be obtained as close together as desired, and in some instruments even continuously. The band pass of a true spectrophotometer is usually held to 10 millimicrons or less.

An abridged spectrophotometer isolates the various regions of the spectrum by means of a series of filters. Usually these filters pass from 40 to 50 millimicrons, although newer instruments have been designed with interference filters that pass about 20 millimicrons. Measuring capacity of an abridged spectrophotometer is limited to the effective wavelengths of the filters built into the instrument. They are usually less than ten. Results from the two types of spectrophotometers most often agree if the curve is smooth. But if the curve has sharp humps and dips, the abridged instrument will not yield an accurate curve.

Tristimulus colorimeters are designed to yield directly, or by simple computation, the ICI* tristimulus values—X, Y, Z—from three photocell currents read from meter dials. The three photocells are adjusted by glass filters to respond proportionally throughout the visible spectrum to a linear combination of the ICI distribution curves (see Figure 5 in October issue). Obviously, if the same accuracy exists, it is advantageous to directly read standard observer tristimulus values rather than compute them from color curves. The difficulty, however, has been to design filters to exactly duplicate the ICI standard observer. The red filter has presented the biggest problem because of the double hump of the ICI $\overline{x}$ function. Tristimulus meter filters pass a light band, broad compared to those in an abridged spectrophotometer. Hence the tristimulus unit cannot usually yield meaningful color curves.

Geometry

Before considering the three classes of color

* *International Commission of Illumination.*

THREE CLASSES OF COLOR INSTRUMENTS

FIG. 1. THE SPECTROPHOTOMETER: This latest model of General Electric's Recording Spectrophotometer draws a curve that is a complete and exact specification of a color. It measures transmittance or reflectance with a photometric accuracy of 1.0 per cent, its photometric precision is within 0.2 per cent, and it operates with a bandwidth of 10 millimicrons through the visible spectrum of 380 to 700 millimicrons. Reflectance curves are drawn on a basis of magnesium oxide as standard.

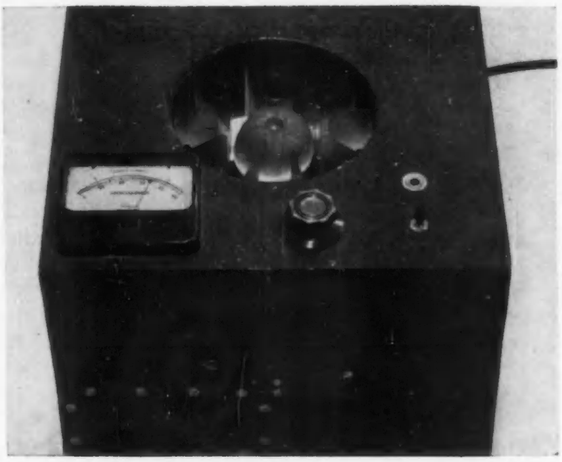


FIG. 2. THE ABRIDGED SPECTROPHOTOMETER: Purdue University developed this inexpensive color meter for field grading of fruits and vegetables. The specimen is placed in a holder lit from below by a circular fluorescent lamp and surrounded by a ring of evenly spaced filter-photocell combinations. Its reading is thus proportionate to average surface color. The unit uses alternate red and yellow filters on tomatoes and apples and indicates the ratio of reflected red to reflected yellow on a 0 to 100 direct reading scale.

FIG. 3. THE TRISTIMULUS COLORIMETER: Gardner Laboratory's unit uses three filters with spectral transmission characteristics similar to the color reaction of an ICI standard observer. The instrument is first standardized against a calibrated reference title. The sample object is then placed inside the exposure chamber (top). Three readings are taken by adjusting three calibrated dials to zero galvanometer positions. These are converted to ICI coordinates by simple formula. A new Gardner unit has automatic, servo-positioned dials.

instruments in detail, a word about the "geometry" of color measurement.

The color of an object generally depends on the way it is illuminated and viewed. True, if the object has a perfectly mat or diffuse surface this rule does not hold. But most surfaces display some gloss or luster. In making a visual examination of a color we tend to avoid surface glare by turning the object until the glare is gone. Color measuring instruments are designed to avoid glare by rejecting the mirror reflection from a surface.

The method of illuminating and viewing a sample is referred to as "geometry". Two different geometries are in general use in colorimetry. In one the sample is illuminated at an angle of 45 deg and viewed from the perpendicular. In the other the sample is illuminated with diffuse light and then also viewed from the perpendicular. It has been shown that the reciprocals of these geometries are equivalent—that is, 45-90 deg geometry is equivalent to 90-45 deg—although they generally will not give identical results. Geometry such as 45-90 is accomplished by directed light beams; diffuse geometry, by an integrating sphere.

SPECTROPHOTOMETERS

At present, the two spectrophotometers most often used for evaluating color of industrial products are the General Electric Recording Spectrophotometer and the Beckman Spectrophotometer. The Beckman instrument, until recently a non-recording transmittance type, is now available as a recording instrument with an accessory that permits spectral reflectance measurements. The General Electric instrument (orginally designed by Hardy) has given great impetus to colorimetric analysis and specification because of its speed—faster than non-recording types—and because spectral reflectance can be measured as readily as transmittance. The instrument is shown in Figure 1, and its schematic workings are described in some detail in Figure 4.

An automatic tristimulus integrator was recently made available by GE as an accessory to its Recording Spectrophotometer. This accessory is incorporated into the instrument so that tristimulus values are read from three dials immediately upon the completion of a curve. To fully appreciate the time and energy saved by this device one must understand what is actually involved in a graphical evaluation of the integrals given in the last sections of the first part of this article (October issue, page 83). If we choose wavelength intervals of 10 millimicrons to evaluate $X = \int E R \bar{x} d\lambda$, we must multiply E by R by $\bar{x}$ at 400, 410, etc., on up to 700 millimicrons—or perform 31 multiplications and add the results. The same must be done to obtain Y and Z, or 93 multiplications altogether.

Many short-cut schemes have been devised for rapid tristimulus value calculation, including planimeter types of mechanical integration and the use of card-programmed electronic computers. But none can rival the speed and convenience of an integrator that derives its spectral data directly from the spectrophotometer while the curve is being drawn, and supplies the tristimulus values as soon as the curve is completed. The technique brings true color measurement very close to being practical in continuous feedback control systems.

The Rapid Scanning Spectrophotometer of the American Optical Co. is of special interest because of its great speed and its unique feature of color curve presentation on the screen of a cathode ray tube. The unit plots a complete spectrophotometric curve 60 times per sec, thus representing another practical way to study and perhaps automatically control industrial process color. Proposed applications for the AOC spectrophotometer include studying rapid changes in chemical or biological materials, monitoring flowing processes to detect and analyze changes, and inspecting certain foods.

ABRIDGED SPECTROPHOTOMETERS

Abridged spectrophotometry is most useful when a process involving color can be reduced to one or two variables. It has already been observed that abridged instruments do not give reliable spectrophotometric curves except in special cases. Actual examples of the abridged method will best illustrate its degree of usefulness.

Purdue University studies of color grading of tomatoes revealed that as the fruit ripens from green to red, maximum changes of reflectance occur at wavelengths 560 and 640 millimicrons. Color at 560 is yellowish-green, and here reflectance decreases with ripening. Color at 640 is red, and here reflectance increases with ripening. Hence the ratio of reflectance at 640 to that at 560 millimicrons is a sensitive index of the degree of ripening of tomatoes—being small for a green or poorly colored fruit, and large for one that is red ripe. An abridged instrument, see Figure 2, was subsequently designed to these specifications.

Another example is furnished by the paper industry. The spectral reflectance curve of unbleached sulfite pulp starts at a relatively low value of 400 millimicrons, rises rapidly in the region between 400 and 500, and tends to level off to a fairly high value at 700 millimicrons. After bleaching, the curve is higher throughout the whole spectrum, but its rise is much greater in the blue region than in any other. Consequently, a reflectance in the blue region is considered a sensitive index of the degree of bleaching. The paper industry has standardized on reflectance as measured by a General Electric reflection meter at an effective wavelength of 458 millimicrons for this index. It is referred to as paper makers' brightness.

In both examples cited it was necessary to conduct a preliminary investigation based on complete

HOW GE'S RECORDING SPECTROPHOTOMETER WORKS

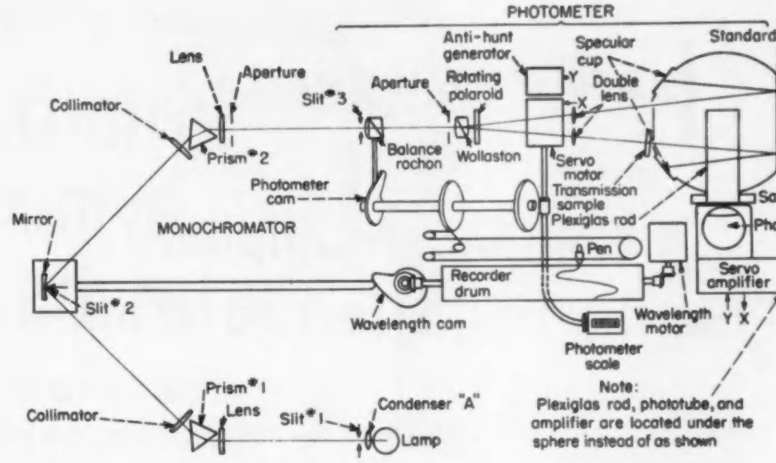


FIG. 4. In this schematic diagram of the General Electric instrument, prism 1 disperses light from the lamp into a spectrum appearing in the plane of slit 2, which isolates a narrow band of wavelengths and passes it on to prism 2. This second prism disperses stray light into a secondary spectrum in the plane of slit 3, which passes only the spectral band isolated by slit 2. Slit 2 is linked to a wavelength drum on which chart paper is placed. The two are activated by a motor that moves slit 2 through the spectrum and turns the wavelength drum. As the spectrum is traversed the mechanical widths of the slits are continually changed to transmit a constant band of wavelengths, usually 10 millimicrons.

The monochromatic light transmitted by slit 3 passes in turn through (1) a balancing Rochon polarizing prism, (2) a Wollaston prism, where it is split into two beams polarized at right angles to each other, (3) a rotating Polaroid polarizer driven by a synchronous motor, (4) decentering lenses, (5) transmission compartment, and (6) integrating sphere—and is incident upon the reflecting samples at B and C.

As the Polaroid rotates, the intensity of the light incident upon B and C alternates between maximum and minimum in such a way that B is maximum when C is minimum, and vice versa. The effective frequency of the alternating component is 60 cps.

A photoelectric cell at the bottom of the sphere is connected to an ac amplifier and a servomechanism so that any alternating current from the photocell will drive the balance motor connected to the Rochon prism. The ac current phase will depend on which of the two energies reflected from B and C is greater. The balance motor is phased to reduce the ac signal to minimum and thus bring about a balance of energies reflected from B and C. When this is accomplished there is no torque on the motor, and it is at rest. The balancing Rochon is mechanically linked to a recording pen assembly, translating its angular setting into pen movement.

When a reflectance curve is to be drawn, the test sample is clipped into opening B and a freshly smoked magnesium oxide surface is clipped into opening C. Complete curves can be drawn in 1 or 2 min at the choice of the operator. For transmission curves, both B and C are covered with high reflecting materials such as magnesium carbonate or oxide and the transmission sample is inserted on the opposite side of the integrating sphere. Typical charts and curves were shown in Figure 3 in the October issue, page 80.

spectrophotometric curves. This is usually the case when an abridged method is sought. It is instructive to note that color, in the full sense of the word, was not the property measured in these cases. Rather, the complete color was reduced to a single variable—a ratio of two reflectances in one case, and a single reflectance in the other.

TRISTIMULUS COLORIMETERS

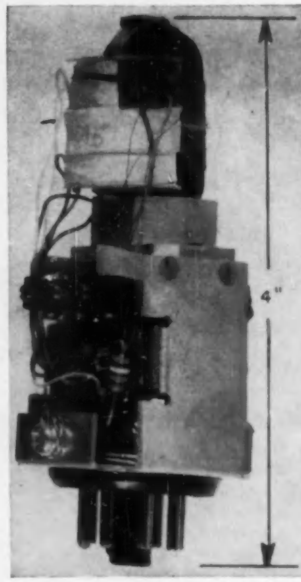
The tristimulus filter colorimeter (see Figure 3 for a well-known example) was developed to incorporate some of the advantages of the spectrophotometer in an instrument that reduces the work of calculating the numerical specifications of color. Tristimulus colorimeters are generally more portable than spectrophotometers, cost less, and require less interpretation of results. Their accuracy, however, depends upon the fit between the theoretical response of the ICI primaries and the response achieved by the combination of light source, filter, and photocell; in no case is this accuracy perfect.

Results become increasingly uncertain as the color difference between standard and sample grows, and when the shape of the spectrophotometric curve for the standard differs appreciably from that of the test sample.

Concerning the first, the tristimulus meter should be operated against a standard that is nearly the same color as the sample to be tested—not always an easy requirement to meet. And to further explain the second, two colors may form a satisfactory match under one illuminant, but have curves that cross over each other in complex fashion. Such colors are said to match metamerically, or form a metameric pair. Generally, such a pair will not match under another illuminant. Non-metameric colors are those with color curves of similar shape. For best results with a tristimulus colorimeter the standard and sample should be non-metameric with respect to each other—also not an easy requirement to meet.

Tristimulus colorimeters have been compared with color deficient persons since they do not see color in the same way as the ICI standard observer.

A Compact Multiplier Puts the Hall Effect to Work



Amps $\times$ gausses $=$ volts when the Hall effect is at work, and this is the basis for a 4-in.-high experimental plug-in multiplier.

GLENN L. KEISTER,
Boeing Airplane Co.

When a metal carrying an electric current is placed in a magnetic field, a voltage is induced perpendicular to the direction of the current flow and the magnetic field. This effect was first discovered by E. H. Hall in 1879, and is illustrated in Figure 1. The electric field, applied in the X direction, and the magnetic field, in the Z direction, induce a voltage in the Y direction. The Hall coefficient determines the magnitude of the Hall voltage for a given conductor and is classically defined as

$$R_H = \frac{1}{nec} \qquad (1)$$

The expression for the Hall voltage is

$$V_H = R_H \frac{BI}{t} \qquad (2)$$

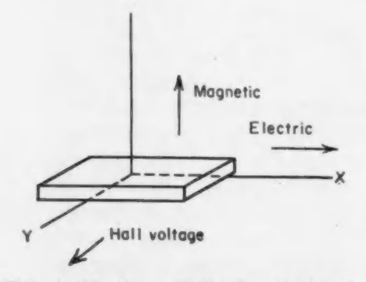


FIG. 1. The basic Hall effect is the displacement of a current in a conductor by a magnetic field. This displacement causes to cross the conductor a voltage gradient that is a product of the current in the conductor and the strength of the magnetic field.

The classical definition for the Hall coefficient would make it simply proportional to the resistivity of the material and of a sign that indicates an excess of either electrons or holes (absence of electrons). This is a simplified conception of what the Hall coefficient is in practice, however, as the value is determined in the laboratory according to

$$R_{Lab} = 10^8 \frac{V_L t}{B I_L} \qquad (3)$$

The coefficient is given from the above in units of cm^3 per coulomb. V_L will be stated as either positive or negative, depending upon the polarity of the Hall voltage, which indicates the predominance of holes or electrons as current carriers.

The Hall voltage is generally quite small and must be separated from other voltages that may appear at the Hall probes. These voltages are due mainly to the electrical misalignment of the Hall probes. Also, certain thermomagnetic and galvanomagnetic effects may contribute slightly to these contaminating voltages.

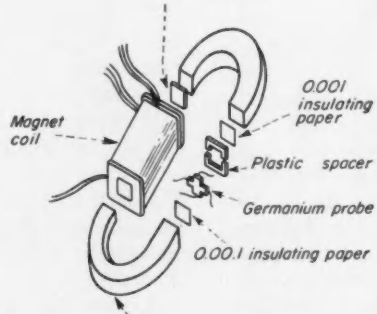


FIG. 2. The heart of the Hall unit exploded. Not shown here is the zeroing system which appears in the schematic.

NOMENCLATURE

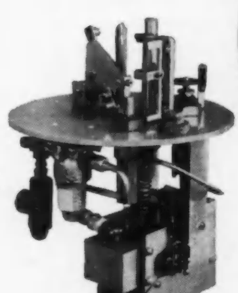
V_L–Hall voltage of R_L
e–electron charge
I_L–strip current in amps of R_L
c–the velocity of light
B–magnetic flux density in gausses
t–thickness of conductor in cm.
n–density of electrons

HOW IT IS USED

The Hall effect has been used to gain information about the density, charge, and mobility of the current carriers of a conductor or semiconductor. Carrier mobility, charge, and density in a conductor can be established by measuring its Hall coefficient and resistivity. Another application has been in the construction of a flux density meter. G. L. Pearson constructed one accurate to 3 per cent from 0 to 20 kilogausses. Mason, Hewitt, and Wick constructed a modulator that utilized the fact that the Hall voltage is the product of the flux density and the strip current. A carrier frequency of 1Kc was applied via the magnetic field and the modulating signal via the strip current. The Hall voltage was the product of the two frequencies or pure double side band modulation.

BUILDING A HALL MULTIPLIER

Looking at Equation 2, we see that



Interior working view

CHARACTERISTICS OF PLUG-IN HALL UNIT

	Channel I	Channel II
Maximum Input Voltage	9.9 v	11.3 v
Maximum Input Current	9.0 ma	46 ma
Maximum Input Power	89 mw	0.52 watts
Input dc Resistance	1080 ohms	246 ohms
Inductance 1000 cps	———	2.26 henries
Dc Zero Shift for no signal in other channel	±1% F.S.	0
Linearity for Maximum Signal in other channel	±1% F.S.	±2% F.S.
Ac unbalance for no signal in other channel	<1% F.S.	<1% F.S.
Maximum Hall emf	0.500 v	
Internal Resistance	2870 ohms	
Maximum Power Out	87 microwatts	

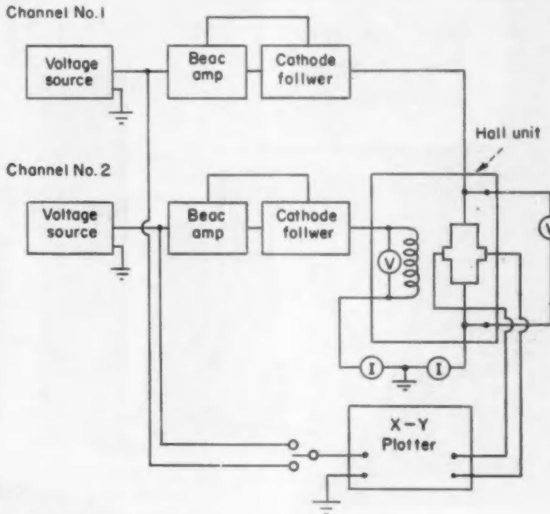


FIG. 3. The circuit used to measure the Hall unit's linearity, and complete performance characteristics.

if B is made proportional to a value e_1 and I proportional to a value e_2, the Hall voltage is proportional to the product of these two voltages. This makes it possible to use the Hall effect for electronic multiplication, and to consider the design of a Hall unit which might serve as an analog computer component. To explore this possibility, a number of plug-in Hall units were built similar to the one shown in the exploded view, Figure 2. Germanium was used for the Hall strip because of its relatively high R_H coefficient of 3.5 x 10^{-4} (most other metals have an R_H of about 1 x 10^{-11}), when obtained in single crystalline form. It was discovered that the loss of crystalline structure sometimes reduced the Hall coefficient of a metal by a factor of 100. Other materials that have large Hall coefficients are Te, Si, and InSb. All of these materials are semi-conductors. The likelihood of silicon crystals in commercial quantities promises Hall strips with much less temperature sensitivity than germanium.

The germanium strip used in the group of plug-in Hall units has a length to width ratio of two and a thickness of from 10 to 30 thousandths of an inch. The current is passed through the length of the strip and the Hall voltage leads attached to the thin edge about half way along its length, as shown in Figure 2. If the length of the strip becomes less than twice its width, the Hall voltage diminishes—the strip current leads tend to short out the Hall voltage. A thinner strip requires less current to produce the same Hall voltage. The circuit used to measure the performance of the unit is shown in Figure 3, and the complete characteristics are tabulated in the accompanying table.

PROBLEMS IN ITS DESIGN

There are some substantial problems encountered in the design of a multiplier using the Hall effect. Its practical accuracy would appear to be limited to variations of R_H due to changes of temperature and flux density, plus the hysteresis of the electromagnet used. However, it was also discovered that the ohmic balance point shifted about 2 mv for a Hall output of 100 mv, and was highly susceptible to temperature variations.

The problem of magnetic hysteresis can be countered by varying the volume of the air gap, the magnetic material used, and the maximum flux density which appears in the gap.

As mentioned, the temperature sensitivity of germanium suggests the use of silicon as a more stable substitute. Other approaches to the thermal problem employ the core of the electromagnet as a heat-sink, using only a thin layer of some good electric but poor thermal insulator between the strip and the core. Aside from the non-linearity produced on the strip, a variety of thermal effects generates small voltages that may also contaminate the output unless prevented or compensated for.

With ac operation some means of balancing out the inductive pick-up in the Hall leads is required. This can be accomplished with a two-turn center-tapped coil shorted with a potentiometer in series with the Hall leads, as shown in Figure 4.

Compensation for magnetic hysteresis and changes in R_H with flux density are possible by placing two Hall strips in the magnet's field and using the Hall voltage from the second strip to control the flux density by means of negative feedback to the electromagnet's power source. However, constructing such an arrangement revealed that temperature induced zero shift could not be eliminated. Figure 5 illustrates the output versus temperature of a double-strip Hall unit. If the zero shift is subtracted out, we find that the control circuit held the output to within 3 per cent full scale. This suggests that where there are

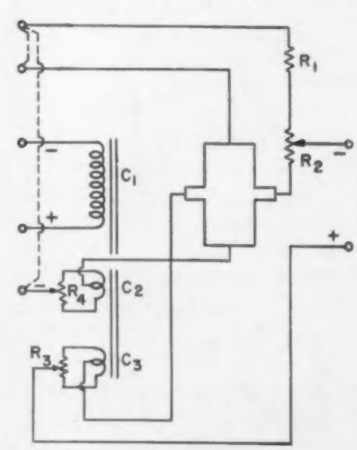
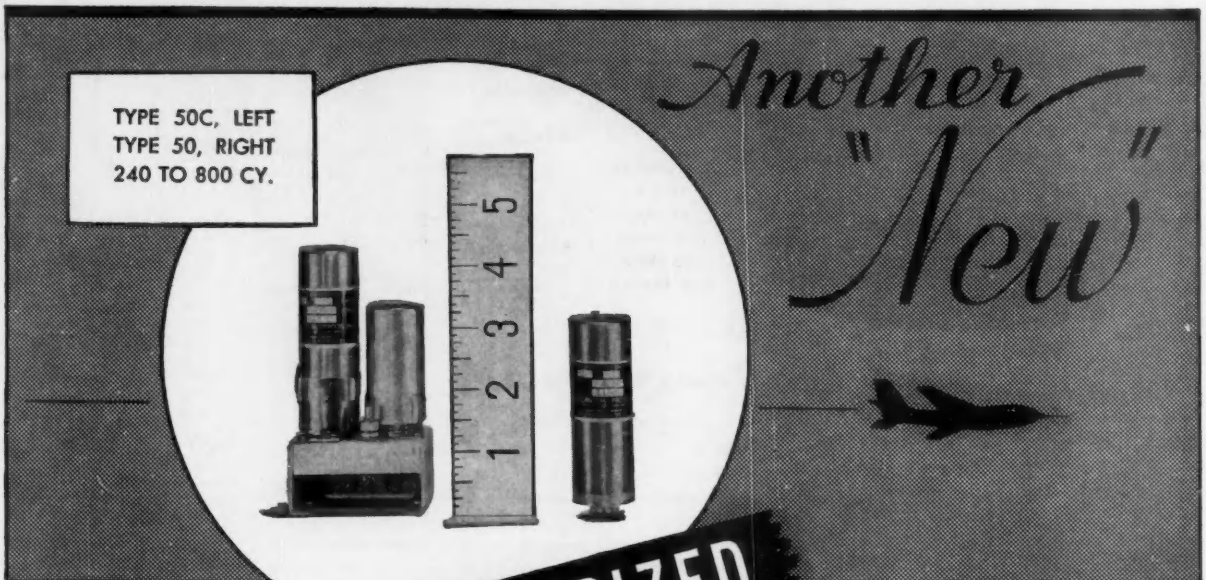


FIG. 4. Circuit within the plug-in unit. Two-turn coil bucks out induced ac which might be generated in leads.



SUBMINIATURIZED

Introduced here are miniature versions of our popular Type 2003. They have equivalent accuracy but are much smaller, lighter and have fewer component parts. In the Type 50, all critical components are housed within the fork container.

Both the Types 50 and 50C offer superior shock resistance, up to 60 G. Hermetically sealed and shielded.

When requesting information, please state type number.

Precision

FREQUENCY STANDARDS ■ AND PRECISION FORKS

PICTURED AT LEFT, ABOVE

TYPE 50C SPECIFICATIONS

SIZE....2 ¼" x 2" x 4 ⅜" high. WEIGHT....8 ozs.
ACCURACY............±.02% from —65° to 85°C
OUTPUT.............................5V into 250,000 ohms
TYPE R50C......................Same as Type 50C with accuracy of ±.002% from 15° to 35°C

PICTURED AT RIGHT, ABOVE

TYPE 50 SPECIFICATIONS

SIZE....1" dia. x 3 ¾" high. WEIGHT....3.5 ozs.
ACCURACY............±.02% from —65° to 85°C
OUTPUT.............................5V into 250,000 ohms
TYPE R50..........................Same as Type 50 with accuracy of ±.002% from 15° to 35°C

For 17 years this company has produced precision frequency standards for integration in highly accurate instruments and timing devices of our own and other manufacture. We make frequency standards within a range of 30 to 30,000 cycles, a field in which we offer maximum accuracy, simplicity and durability. Our products are now serving in many and varied applications—in industry, government (including the armed services, particularly in the field of aviation) and for laboratory uses.

IF YOU HAVE A FREQUENCY PROBLEM AND WILL DESCRIBE IT, WE SHALL BE PLEASED TO SUBMIT OUR RECOMMENDATION TOGETHER WITH PRICE QUOTATION

American Time Products, Inc.

580 Fifth Avenue ***New York 36, N. Y.***

OPERATING UNDER PATENTS OF WESTERN ELECTRIC COMPANY

temperature variations, a germanium Hall multiplier will require an oven. The double-strip set-up brought the accuracy of the unit to within 1 per cent full scale with constant temperature, however. This is roughly double the accuracy of the single-strip multiplier.

MORE USES

There are other uses for a Hall unit aside from multiplication. It can be substituted for a mechanical chopper in a dc amplifier, with the advantage of much higher operating frequencies. Since the Hall unit is a low voltage, current device, it may be more compatible to magnetic amplifiers than vacuum tube devices. Preliminary experimentation in this direction indicates that the Hall unit can drive a differential magnetic amplifier.

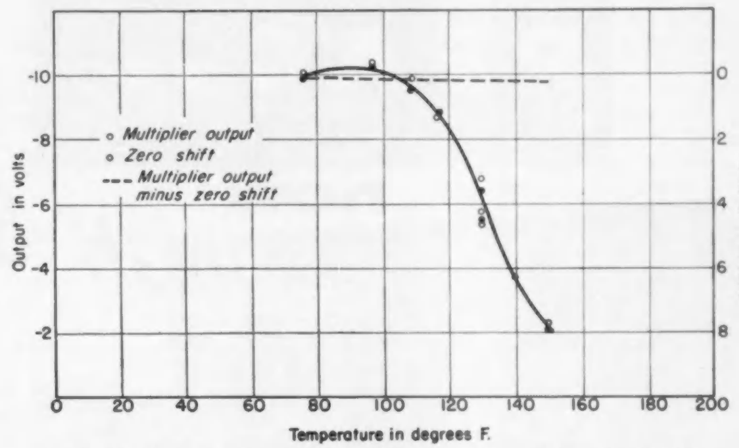


FIG 5. Temperature sensitivity of the germanium Hall unit with two strips, one used for feedback to the flux source to cancel out changes in R_H due to flux and changes in flux due to hysteresis. This curve shows that the zero shift still looms large as a source of non-linearity.

Converts Morse Code to Printed Copy

The TRAK Morse Code Converter accepts coded signals from a regular radio receiver and translates these signals into suitable electric pulses, thus forming the message text for readout on an automatic typewriter.

Actually, the converter receives code in these two forms:

▶ Output of a radio receiver or tone line as a keyed audio tone; or

▶ Hand or automatic keying as a keyed dc voltage.

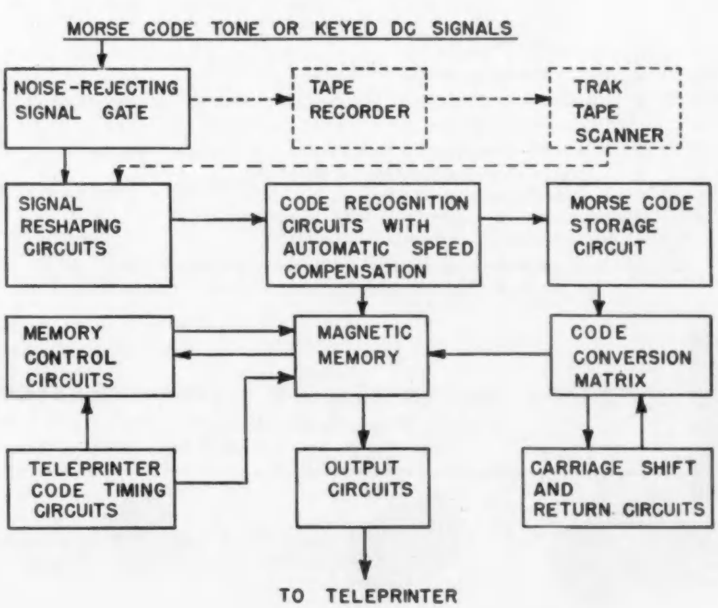
A Morse code input signal follows this path through the converter unit:

▶ The signal goes into a static rejector and then into a Morse code regenerator circuit.

▶ From here, it feeds into a recognition circuit that distinguishes between dots, dashes, spaces, and the end of a letter or a word—all this independent of the speed of transmission.

▶ Then the signal feeds into a one-character memory stage—this first storage circuit remembers each character component until it is completed.

▶ From this memory stage the signal goes into a conversion matrix circuit, where it is translated into its corresponding page printer pulse group.



The TRAK converter is a product of CGS Laboratories, Inc., Stamford, Conn.

▶ The pulse group goes into a second storage circuit—but here a magnetic memory retains ten pulse-coded characters to operate the teleprinter.

▶ Then the second memory stage keys the final stage, transmitting the stored printer pulses to the input leads of a standard teleprinter or to other equipment, such as a reperforator.

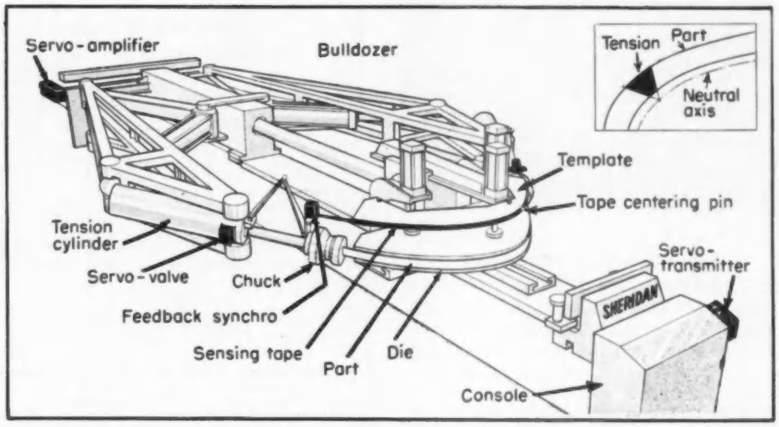
In the first memory stage, the equipment lags by one character. This gives the system time to recognize the complete character and control the additional operations of the various circuits. In this process, the circuit samples the length of the character as well as its dots and dashes to determine whether it is a letter or a number.

As soon as the recognition circuit determines that the next character to be printed is a *number*, the circuit generates a pulse (information not present in the original signal) to raise the carriage of the printer. And, of course, at the end of a number code, the printer receives another pulse that tells it to return to lower case carriage.

Synchros Control Stretch

R. D. ATCHLEY, Raymond Atchley, Inc.

With a template somewhat smaller than the forming die guiding the measuring tape, a simple synchro position servo system can accurately control elongation on a 50-ton stretch press, despite varying friction and part cross section.



In a stretch press, the part to be formed is clamped tightly between the tension cylinders, wrapped around the die and elongated as the die is pushed into it by the bulldozer.

Stretch presses like that shown in the figure are useful for forming bends and curves in long metal parts and find extensive application in the aircraft industry. The part to be formed is wrapped around a male die under such tension that the neutral axis of bending is entirely outside the part (insert). The part is then further stretched beyond the yield point of the metal by the tension cylinders.

STEPS IN STRETCH FORMING

At the start of the forming operation the "bulldozer" that carries the forming die is completely withdrawn to the rear of the machine. The part, still straight, is chucked tightly between the tension cylinders, which are at right angles to the bed of the press. Then the bulldozer moves forward, causing the tensioned part to be wrapped around the forming die and the tension cylinders to move to the position in the figure.

Before the days of servo controls, a great deal of skill and knowledge of the process were required of the machine's operator, and even then the results were liable to be erratic. The operator stood at the console at the front of the machine and, while the die moved forward at a constant rate, attempted to control the hydraulic pressure in the tension cylinders. Because the force necessary to make a part yield without fracturing varies considerably from part to part with cross-sectional area and metallurgical properties, manual control of this kind was difficult. Also, the forces applied by the tension cylinders at any given pressure varies with friction in the packing. Thus, manually controlled stretch presses meant nonuniform product and poor repeatability.

POSITION CONTROLS STRETCH

Electrohydraulic position servos were the answer to accurate stretch press control.* At the start of the automatically controlled operation, the part to be formed is tensioned between the tension cylinders, just as in the manual operation. But now, as the figure indicates, a measuring tape is also stretched between the tension cylinders. Each end of this tape wraps around a synchro shaft that rotates as the tension cylinders are drawn apart, and stops when the full amount of pre-tension has been applied to the part. At this point each synchro is switched into a null position electrohydraulic servo system, which seeks to maintain the synchro shaft position and thus hold the tape constant as the bulldozer is moved forward.

Because the measuring tape is wrapped around a template that is somewhat smaller than the forming die, the part must stretch around the die if the tape length remains constant. The neutral axis of bending, in line with the tape, lies entirely outside the part, and the tape neither stretches nor compresses. After the bulldozer has been stopped by a limit switch, the synchro is switched out of the position servo system and the part is given a small post-elongation by the tension cylinders to remove any tendency to spring back upon removal from the press. This automatic position control eliminates the problems created by varying friction, cross-sectional area, and metallurgical properties, and makes stretch forming a dependable, repeatable operation.

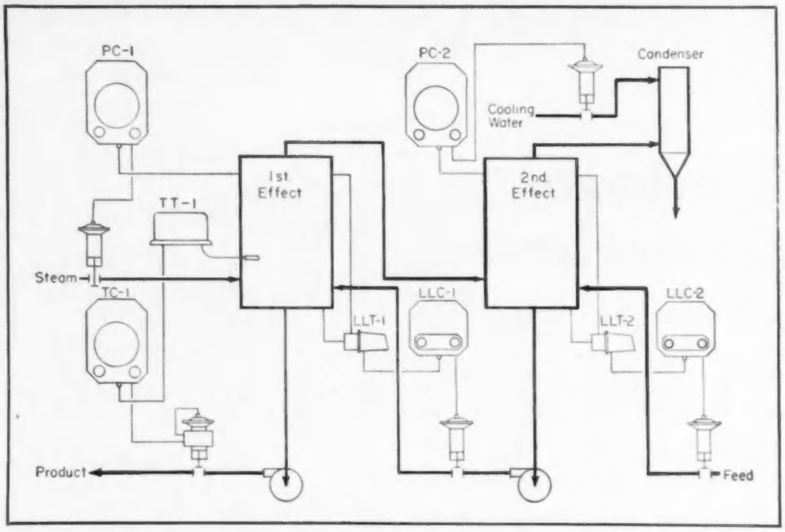
* *Pat. Appl'd For by Sheridan-Gray, Inc.*

EVAPORATOR CONTROL

One of a series of basic instrumentation recommendations for the unit operations

GEORGE E. HOWARD, Manager
Application Engineering Dept.

"The success of the Taylor approach to evaporator control is due to our engineers' knowledge of how an evaporator works and the problems involved. This experience has been gained through years of working with widely diversified industries. Data sheets on this and other evaporator problems are available on request."



PROBLEM

To operate the evaporator to produce a uniform product of the optimum concentration at the lowest possible cost. And with a minimum of operator attention and maintenance.

SOLUTION

(*see diagram*) On body #1 the FUL-SCOPE* Pressure Controller (PC-1) insures stable pressure conditions in the body, despite steam supply variations, fouling of tubes or changes in product rate. It also provides a record for correlation with solution temperature.

The TRANSAIRE* Transmitter (TT-1) senses boiling temperature as a measure of concentration, since pressure is maintained precisely. SPEED-ACT* in the measuring circuit insures practically instantaneous response.

The Temperature Controller (TC-1) records and controls boiling temperature and regulates discharge rate to maintain precisely the desired concentration.

*Trade Mark

The Level Controllers (LLC-1 and 2) maintain flow of the solution through the evaporator in proper relation to the discharge rate. They insure optimum use of the heating surface and considerably reduce tube fouling.

Piping costs and maintenance can be minimized by using Differential Pressure Transmitters (LLT-1 and 2) close coupled at the point of measurement. Yet the receiving level controllers can be located at a convenient centralized spot. Where purges are necessary, the double process connections on the DP Transmitter permit the meter body as well as the lines to be purged.

The Pressure Controller (PC-2) measures and controls absolute pressure (corrected for barometric pressure) in the final effect by regulating flow of cooling water to the condenser. This assures stable operation, despite variations in cooling water pressure or temperature or fouling of tubes in the 2nd effect. In cases where cooling water supply is limited, it conserves condenser water requirements by maintaining the minimum quantity necessary for best operating conditions.

Evaporator rate may be changed easily with a minimum of upset to concentration control, simply by adjusting the control point of PC-2.

SUMMARY OF BENEFITS

A control system such as this will pay for itself in a short time by:—

1. Prolonging the period between clean-ups.

2. Insuring steady output of uniform product, even with erratic supply.

3. Maintaining steady steam demand.

4. Cutting operator attention time to routine observation, thus releasing trained personnel for more productive duties.

• • •

Send for Data Sheet #10 covering the recommended instrumentation for multiple effect evaporators in greater detail. And remember, whatever your problem in instrumentation, Taylor Field Engineers are ready, willing and able to serve you. Taylor Instrument Companies, Rochester, N. Y., and Toronto, Canada.

***Taylor Instruments* MEAN ACCURACY FIRST**

Optical Servo Detects Refractive Index to One Part in 100,000

J. W. FORREST, H. W. STRAAT, A. A. SHURKUS*, Bausch & Lomb Optical Co.

* Now at Applied Research Labs, Glendale, Calif.

A precision refractometer produces a chart record of refractive index deviations in a *flowing* sample and, through a standard pneumatic controller, maintains refractive index at a desired value. Unique techniques are:

- **an optical servo**
- **automatic phasing of synchronous motor**
- **means of using commercial amplifier and recorder-controller**

Refractive index, one of the physical characteristics of a translucent liquid, is a measure of purity or concentration. Common discrete-sampling refractometers measure the position of the borderline of total reflection between a prism of known characteristics and the sample. While results are excellent with a discrete-sampling instrument, difficulties arise in continuous sampling because the sample is usually in the form of a thin flow-restricting film. A second, and not so common method, is to let the liquid sample flow through a hollow prism of glass. Now the angular position of a slit image with respect to the prism face is the measure. It has these definite advantages:

- Motion of the slit image in either direction is a concrete signal
- Prism configuration minimizes the flow restriction

The optical system, shown in Figure 1, is similar to that of a conventional prism spectrometer. It has a basic index range of 0.2 (1.25 to 1.45), which may be raised or lowered as required by a fixed auxiliary prism of suitable value. Light from an illuminated slit is collimated by an achromatic lens, refracted by the hollow sample prism (1), and brought to a focus by a telescope lens to produce a sharp slit image. The Amici prism (15) corrects for residual dispersion and gives a slit image reasonably free of color. Adjustable in rotation, it may be set for materials with varying dispersions. The hollow sample prism (1) consists of two glass elements, their indices and angles so chosen that deviation within the desired index range is symmetrical about the optical axis. The variable prism (3) is made up of two prismatic elements that rotate in opposite directions when balancing the system at a predetermined null.

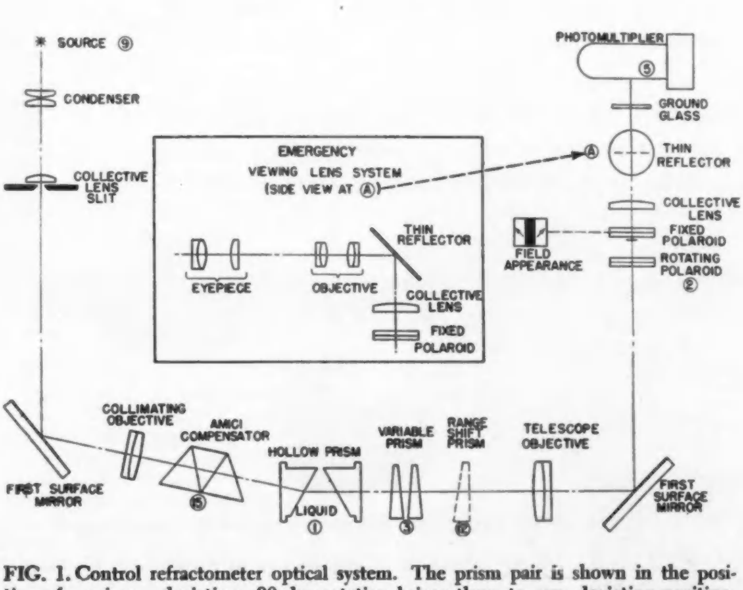


FIG. 1. Control refractometer optical system. The prism pair is shown in the position of maximum deviation. 90 deg rotation brings them to zero deviation position.

OPTICAL SERVO

In the focal plane of the telescope objective is a broad opaque bar separating the two oppositely polarized fields, as shown by the projection labeled "field appearance" in Figure 1. The bar is the fixed optical reference point on which the system balances. Since the width of the slit image is slightly greater than that of the bar, the system is in balance when a thin line of light appears at either side of the bar. If the index of the liquid in the hollow prism changes, the image moves into one field or the other, initiating optical unbalance.

Behind the crossed polaroids of the bipartite field, and rotated at 1800 rpm by a synchronous motor, is the analyzer of the photometric system, Figure 2. When the slit image deviates and produces an optical unbalance, the analyzer develops, at synchronous frequency, an amplitude-modulated sinusoidal variation of light intensity. As this variation is directed at the photomultiplier's cathode, the photomultiplier delivers a proportional voltage to the Leeds & Northrup ac amplifier. The amplifier drives the balance motor to restore the system to its optical balance point. The viewing lens system (insert in Figure 1) is intended for preliminary set-up work but may also be used to guide the system manually in emergencies.

The balance motor powered by the ac amplifier drives three elements:

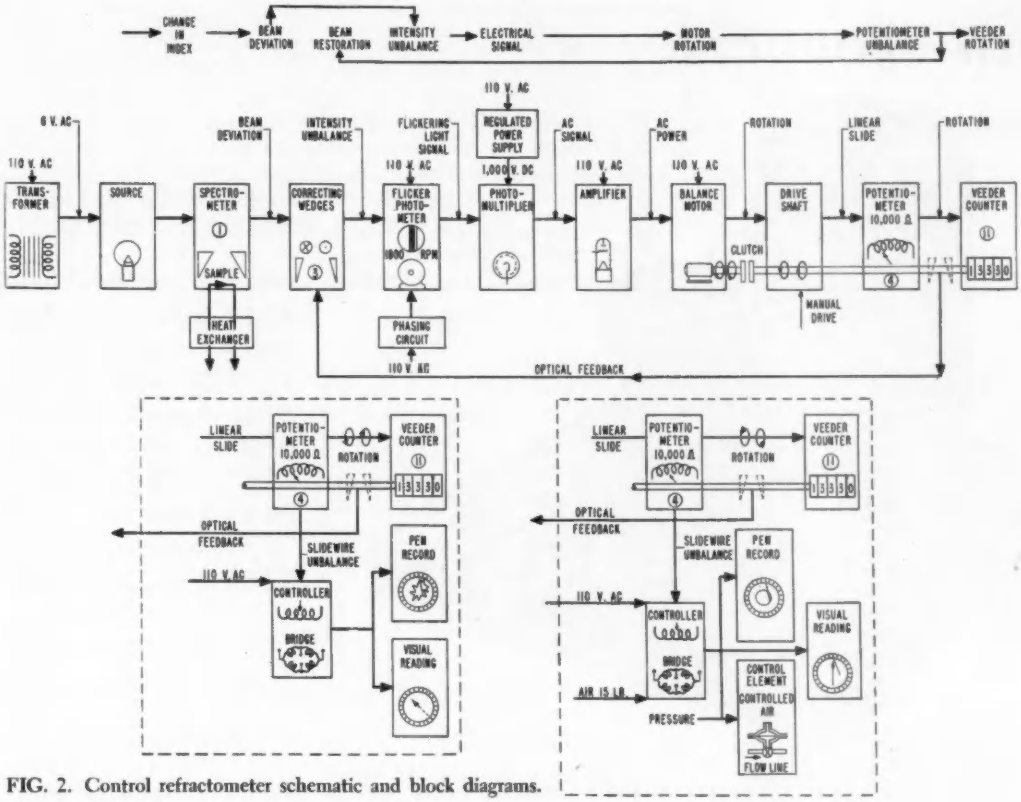


FIG. 2. Control refractometer schematic and block diagrams.

▶ Potentiometer (4), the link between the refractometer and a Brown recorder-controller

▶ Veeder counter (11), which provides a reading of the refractive index to one part in 100,000

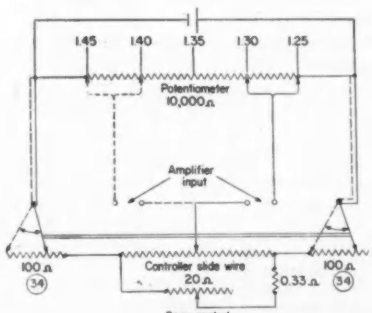


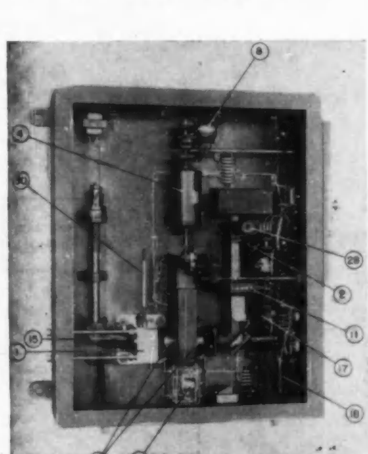
FIG. 3. Linking Wheatstone Bridge. Setting the series resistors (34) at 94.34 ohms (right) and 13.48 ohms (left) locates the balance point of the potentiometer at the midpoint of the bracketed section at the upper right of the diagram when the balancing slidewire is centered. This point is optically equivalent to an index of 1.27500. With the span-setting resistance at 7.816 ohms the zero per cent scale line of the recorder chart represents an index of 1.26775 and the 100 per cent scale line represents an index of 1.28225.

▶ Screw and nut assembly, which rotates the elements of the variable prism (3) for optical feedback.

AUTOMATIC MOTOR PHASING

So that the system will drive toward the balance point from either the high or low side, the synchronous flicker motor must be properly phased with reference to the optical system. This phase is corrected by connecting a resistance across the condenser terminals of the synchronous motor, making its rotor slip. A small generator driven by the motor shaft energizes a sensitive relay when the motor locks in the wrong phase, the relay cuts in the resistance described, and the rotor slips until the phase is correct. The generator then ceases to deliver current to the relay armature and the relay opens. The whole operation is almost instantaneous with the closing of the switch.

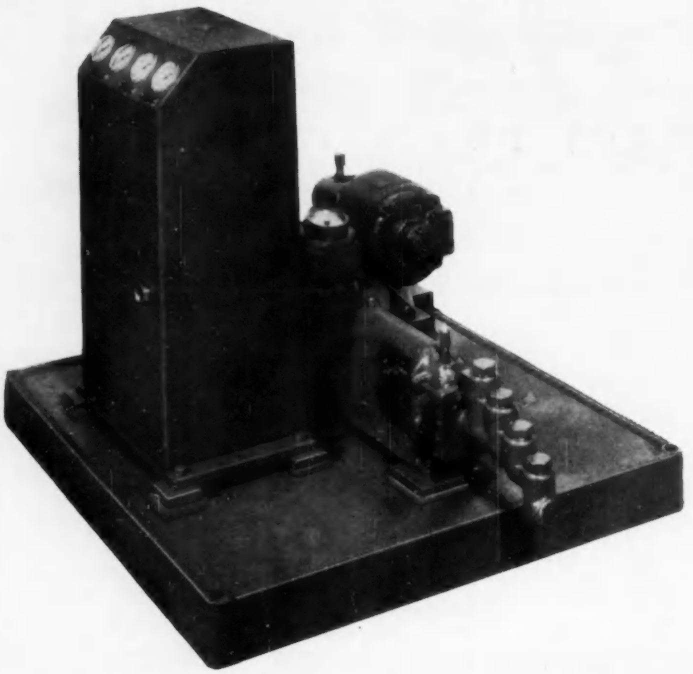
FIG. 4. Assembled precision refractometer for measurement of continuous samples. Circled numbers identify same items shown schematically in Figures 1 and 2.



LINK TO RECORDER-CONTROLLER

Through the Wheatstone Bridge circuit shown in Figure 3 the 10,000-ohm potentiometer (4) links the motion of the variable prism (3) to the mechanism of the commercial recorder-controller. The potentiometer constitutes two arms of the bridge and the 20-ohm sidewire of the recorder, the other two. The manually adjustable resistances in series with the slidewire locate the operating section of the potentiometer. And a 25-ohm slidewire in parallel with the recorder's slidewire determines span.

NEW PRODUCTS



LISTING IN GROUPS

ADJUSTABLE STROKE plus variable speed motor equip this pump to accurately move the product of two variables.

Inside the solid-looking control console above is a pneumatic servo that controls the stroke length of a pump. Its operation is block-diagrammed below.

Behind the 2-ft-high console is a pump whose stroke-length adjustment assures accurate output in controlled quantities. The servo determines the stroke length according to a pneumatic control signal (within the conventional 3 to 15 psi range). Since the motor driving the pump operates on dc, it is possible to vary pumping rate by altering its speed. Consequently, two variables can be accounted for in the resultant fluid rate.

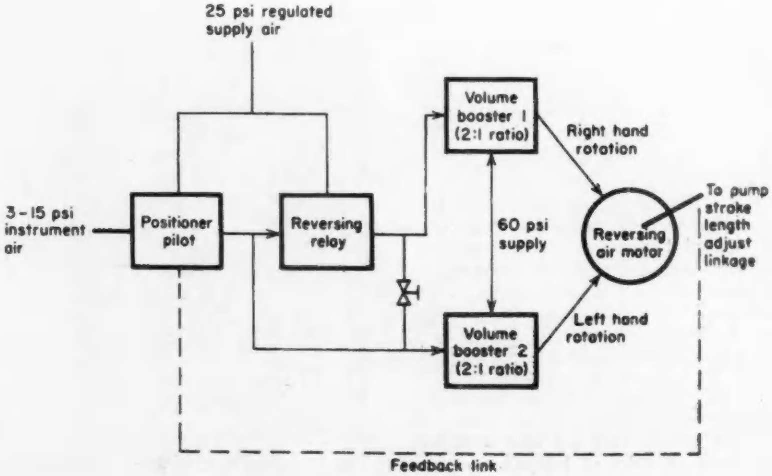
The stroke length adjusting mechanism is a mechanical linkage affair which, says the maker, cannot get out of alignment once it is set. This mechanism can be operated either by a handwheel or by electrically operated stroke length adjusting devices. With this model, every 240 revolutions of the air-motor output of the pneumatic servo produces a 1-in. change in the stroke length of the pump (which has a 6-in. max. stroke).

The instrument air signal (block diagram) is compared with the position of the stroke length adjusting linkage in the positioner pilot. If a condition of balance exists, a 12-psi pressure is produced. Since this is half way through the range of the reversing relay, its output is also 12 psi, and a condition of pressure balance exists on the air motor. If, however, a condition of unbalance exists, the air motor will be driven by volume booster 1 or 2, depending upon whether the unbalance produces a pressure greater or lesser than the 12 psi from the positioner pilot. Any tendency of the air motor to hunt can be eliminated by adjustment of the needle valve between the two volume booster inputs. *Milton Roy Co., 1300 E. Mermaid Lane, Philadelphia 18, Pennsylvania.*

Characteristics

Positioning speed—10 sec per in.
Adjustable stroke length—0 to 6 in.
Positioning accuracy—1 per cent
Sensitivity—1/70 psi
Main supply air pressure—80 psi

Circle No. 1 on reply card



STARTING THIS MONTH . . .

The mounting flood of New Product releases has forced our NP editor to new pinnacles of systematization. One of the results is an attempt to put some long-term value on the divisions that start off this section. The nomenclature used this month is what we'll use every month from now on (plus or minus one or two) and it's hoped that this regularity will help you (and us) to thumb through past issues for a specific product for a minimum of lost time.

Power Sources for Control

MINIATURE SUPPLY is variable, regulated and economical

Small budgets and ambitious specifications may both be satisfied by this 302C portable power supply. Its A and B output are continuously variable, with the A output regulated for variations of line or load. The shoebox sized source can be used in series or in parallel to increase voltage or current output. Included in the price of slightly over $100 is a dual range meter, standby switch, pilot light, and fuse. *Allied International, Inc., Allied Engineering Div., South Norwalk, Conn.*

Characteristics

Ripple—3 mv
Output A—0 to 350 vdc at 80 ma
Output A regulation—within 0.05 per cent
Output B—0 to 150 vdc at 5 ma
Output B regulation—within 1 per cent
Output C—6.3 vac at 5 amps
Input—105 to 125 vac, 60 cps
Recovery time—within 15 ms

Circle No. 2 on reply card

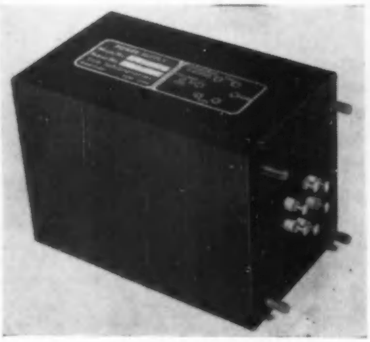
POTTED AND SEALED, packaged power supply fits MIL specs.

Activating circuits having up to three vacuum tubes is the role of this compact tubeless power supply. The two outputs are unregulated. All dimensions are in accordance with MIL-T-27, size HA. The case is completely isolated. Model CP's innards are suspended in a lightweight, foam-type, thermosetting resin. *Trio Laboratories, Inc., 3293 Seaford Ave., Wantaugh, N. Y.*

Characteristics

Input—115 vac, 60 or 400 cps
Output—150 vac at 6 ma
Filament output—6.3 vac at 0.6 amp
Ripple—under 1 mv with 400 cps under 5 mv with 60 cps
Size—2½ by 3 by 4¼ in.

Circle No. 3 on reply card



PLUG IN power supply suited for small instruments.

The Uniplug, a complete subminiature plug-in power supply, has substantial assembly advantages for the makers of small, special purpose instruments. It's priced under $40 and comes in four models, two regulated and two unregulated. The unregulated models offer two voltage outputs and higher current. Data on one model is to the right. *C. J. Applegate & Co., 1816 Grove St., Boulder, Colo.*

Characteristics

Model 215 output—150 vdc at 12 ma
Regulation—within ½ per cent
Ripple—0.004 per cent
Filament supply—6.3 ac at 0.9 amp
Input—105 to 125 vac 60 or 400 cps
Size—2½ by 2½ by 3 in.

Circle No. 4 on reply card

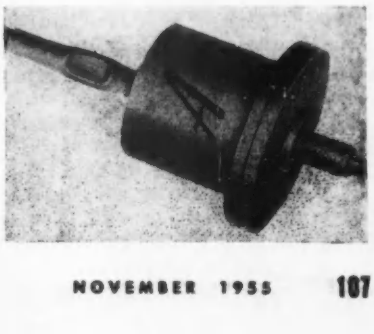
SILICON DIODE offers vast savings in weight and space.

This little diode operates in temperatures as high as 150 deg C. The reverse resistance of the tiny rectifiers is phenomenal: 1,000 megohms. The all-welded hermetic sealing is said to offer life-long protection to the diodes. The rectifiers are said to be 1/55 the size of comparable selenium rectifiers. Six models are available with the characteristics of the most potent shown. *Automatic Mfg. Corp., 65 Gouverneur St., Newark 4, N. J.*

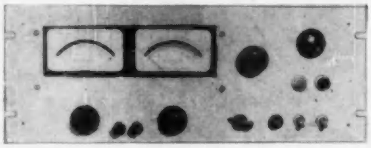
Characteristics

Peak inverse voltage	600
Continuous dc reverse voltage	600
Dc output current (ma)	300
Full load voltage drop	1.0
Reverse leakage current (μv)	0.2

Circle No. 5 on reply card



More Power Sources



HIGH VOLTAGE power supply mounts in two cabinets.

A unique feature of a new high voltage power supply, model R-500A, is its two-part construction. A multi-turn potentiometer is provided for conventional control of output, which is varied through its full range by an external reference control voltage. The meters provided are a kilovoltmeter and a current meter. *Neutronic Associates, 87-16 116th St., Richmond Hill 18, N. Y.*

Characteristics

Output.....**100 to 5,000 vdc at 8 ma**
Regulation...**½ per cent 0 to full load**
Stability........**within 0.25 per cent**
Ripple.........**within 0.05 per cent**
Response time.......**5 ms for 1 to 5**

Circle No. 6 on reply card

LOW COST voltage control

The Varitol is a low-cost, reactor-type voltage variator intended for inclusion in original equipment (1/50 to ⅛ hp shaded pole or split capacitor motors or other low-amp ac devices). Seven models offer continuously variable voltages and generate a fraction of the heat of comparable resistances. *Killeen & Son, Production Engineering Co., 915 E. 59th St., Los Angeles 1, Calif.*

Characteristics

Amp reduction—to approx. ⅞
Amp range—7 models have 1.5 to 7 amp max. output
Size—3 by 4 by 6 in.
Line voltage—115 and 220

Circle No. 7 on reply card

HIGH CURRENT POWER SUPPLY: Model GF offers continuously variable dc up to 125 v at 10 amp continuous, 20 amp intermittant. Ripple is kept under 1 per cent. *Electro Products Laboratories, 4501 N. Ravenswood Ave., Chicago 40, Ill.*

Circle No. 8 on reply card

FIXES VOLTAGE and cps of motor alternators

The VF control is essentially a governor and voltage regulator for motor alternator sets. It enables conversion of dc to ac with precise frequency and voltage regulation. Secret of the machine is a unique electromechanical regulator and a resonant circuit. Standard units, for 60 to 400 cps, hold both voltage and frequency to within 2 per cent, although ½ per cent regulation also is available. *Electric Regulator Corp., 314 Pearl St., Norwalk, Conn.*

Circle No. 9 on reply card

Indicators & Recorders

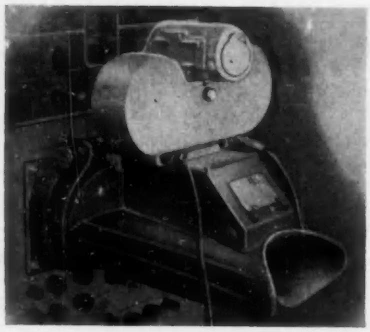
ELECTRONIC RECEIVER cams away nonlinearities.

An interesting feature of this new recorder pen pusher is the cam scheme at the right. Non-linearities in a sensor can be eliminated by cutting a cam to match the pickup's characteristics, thereby making pen motion linear. All special graduated charts are obsolete beside this approach, says the maker; this may cause great woe to chart makers but probably not to chart readers. No small advantage of the compact machine is the fact that four at a time can fit into a conventional circular chart recorder case. Input ranges are 0 to 2 and 0 to 20 vdc. Error is less than ¼ per cent for spans of 10 millivolts or more, and within 25 microvolts for lower spans. Full scale pen motion takes 5 sec. Tolerance on the 115 vac 60 cps power supply is 10 per cent. The maker has a 12 page leaflet on the item. *Bailey Meter Co., 1050 Ivanhoe Road, Cleveland 10, Ohio.*

Circle No. 10 on reply card

BRIDGE BALANCE: A new four-channel bridge balance, Type 8-110, works with 120- to 350-ohm strain-gage bridges or strain-gage type pick-ups to provide the control link between resistive type transducers and such output devices as recorders or meters. Voltage across each bridge can be adjusted individually and continuously from the level of the supply voltage (20 vde max.) down to zero for any four-arm bridge. *Consolidated Engineering Corp., 300 N. Sierra Madre Villa, Pasadena 15, Calif.*

Circle No. 11 on reply card



SCOPE CAMERA offers continuous viewing and time marker.

The film transport rate of the above oscilloscope 35 mm camera may be set between 1 and 300 in. per sec. It features simultaneous binocular viewing while recording and an illuminated identification card and flashing lamp time reference. Film capacity is 100 ft and film consumed in starting and stopping is less than 2 ft. It has an F 1.5 50 mm coated lens. *Brea Instruments, P. O. Box 248, Brea, Calif.*

Circle No. 12 on reply card

FREQUENCY AND AMPLITUDE shown over wide range.

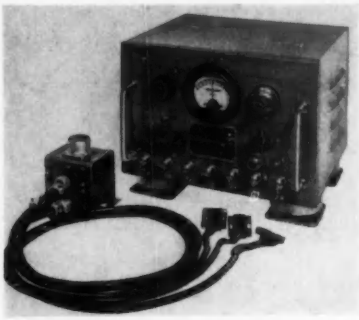
Combining the function of a frequency meter and amplitude indicator, the above instrument will indicate on panel meters the frequency of an incoming signal from 30 to 50,000 cps. Amplitudes ranging from 500 down to 160 microvolts rms are displayed. Features include a double half-lattice crystal filter and a switch for choosing narrow or broad selectivity. The latter is advantageous when scanning the spectrum or when input signals contain small amounts of frequency modulation. *Donner Scientific Co., 2829 7th St., Berkeley 10, Calif.*

Circle No. 13 on reply card

HIGH SPEED strip chart recorder speeds pen at almost 4 ft/sec.

The pen of a new strip-chart recorder requires only a quarter-sec to cover the full 11-in. chart width. The maker says it fills an important gap between oscillographic instruments and slower conventional large chart recorders. Continuous standardization is provided. Basic chart speeds offered are 2 in. per sec or 4 in. per min. An optional chart drive step-mechanism can provide additional speeds. *Minneapolis-Honeywell Regulator Co., Industrial Div.*

Circle No. 14 on reply card



INDUCTANCE MICROMETER senses in the microinch range.

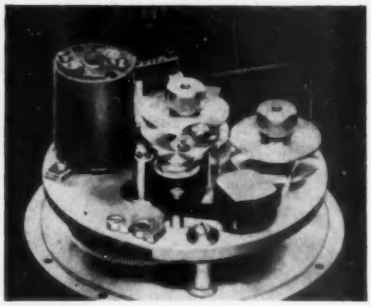
Originally a detector of shaft eccentricity, the above apparatus uses changes in inductance to sense variations in the paths of rotating shafts. Operable at shaft speeds of up to 6,000 rpm, it will work with shaft radii of from 1 to 12 in. Measurements are made with an accuracy of plus or minus 20 microin. Probe to shaft clearance is 2 to 5 mils. This might make a good machine to measure the deflection of rotating elements at high speeds. *Minnesota Electronic Corp., 133 E. Santa Anita St., Burbank, Calif.*

Circle No. 15 on reply card

FAST RECORDER designed for rapidly changing data.

High-speed recorders seem to be in the air. This one whips its pen across the chart in 0.4 sec. The deadband of the instrument is less than 0.1 per cent of the full-scale span. It is offered with standard ranges as low as 1 millivolt for full scale, with source resistance of up to 10,000 ohms. Chart speeds up to 4 in. per sec are obtained with a specially designed pen and carriage. A Thyrite voltage regulator in the field circuit of the feedback damping generator provides constant damping voltage, regardless of line variations. *The Bristol Co., Waterbury 20, Conn.*

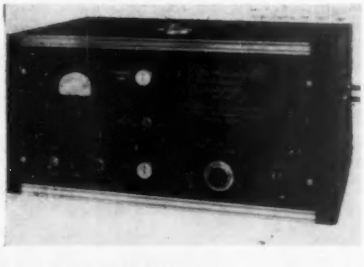
Circle No. 16 on reply card



MINIATURE 'SCOPE packs full-sized features.

The above new cathode-ray oscillograph, the size of a shoebox, is designed for computers and for measuring high speed phenomena. The rise time of its signal amplifier is 0.08 microsec. The maker claims features usually only associated with much higher priced gear. They include calibrated sweeps, a wide-band signal delay line to assure an entire view of the rise of the fastest signals, a calibrated squarewave at the front panel (also suitable for external equipment), and a positive fast-rising gate output at the front panel for triggering other devices. A three times expansion of any calibrated sweep can be switched in. An X amplifier is available for signals that must be plotted on the X axis. Response is down 80 per cent with signals at 8 megacycles. *Allen B. du Mont Laboratories, Inc., 750 Bloomfield Ave., Clifton, N. J.*

Circle No. 17 on reply card



NOISE MAKER offers perfectly confused frequencies.

The above machine provides a ran-

TYPICAL LABORATORY BENCH SETUP shows how simple it is to hook up the input and load connections of the Solavolt for testing a fluorescent ballast at several different input voltages. It has attached input cord and plug, line on-off switch, and three sinusoidal ac voltage outputs, all regulated within ±1%: (1) a standard receptacle for fixed 115 volts (2) a standard receptacle for a variable output of 0-130 volts and (3) a pair of jacks for variable output of 0-130 volts.

±1% Regulated AC Voltage Supply Adjustable from 0 to 130 Volts

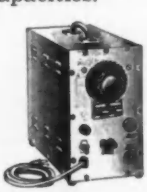
When an adjustable source of regulated ac voltage is required for the accurate performance of a variety of electrical or electronic equipment, a Solavolt is often the simple, practical solution. It provides the close regulating action of a Sola Constant Voltage Transformer (a static-magnetic stabilizer) with less than 3% harmonic distortion of the output voltage wave.

Two of the Solavolt's three outputs are adjustable from 0 to 130 volts. The third provides a fixed 115 volts. All three outputs are regulated ±1% regardless of input changes from 95 to 125 volts, and may be used simultaneously within total maximum va rating.

Regulation is completely automatic and continuous with response time of 1.5 cycles or less. Except for the rotor of the autotransformer, there are no moving parts, and no manual adjustments are required. There are no tubes or other expendable parts.

The Solavolt is an ideal package unit, with carrying handle, where portability and compactness is a factor. It is particularly useful for general laboratory work, instrument calibration, testing, general shop use, or other similar applications. Solavolts are available from your electronic distributor in either 250va or 500va capacities.

SOLA *Constant Voltage* **TRANSFORMERS**



Write for Bulletin 26K-CVL193 for full electrical and mechanical specifications of the Solavolt.

SOLA ELECTRIC CO.
4633 W. 16th St., Chicago 50, Ill.

CONSTANT VOLTAGE TRANSFORMERS for Regulation of Electronic and Electrical Equipment • **LIGHTING TRANSFORMERS** for All Types of Fluorescent and Mercury Vapor Lamps. • **SOLA ELECTRIC CO., 4633 West 16th Street, Chicago 50, Illinois, Bishop 2-1414** • *NEW YORK 35: 103 E. 125th St., TRafalgar 6-6464* • *PHILADELPHIA: Commercial Trust Bldg., RIttenhouse 6-4988* • *BOSTON: 272 Centre Street, Newton 58, Mass., BIgelow 4-3354* • *CLEVELAND 15: 1836 Euclid Ave., PRospect 1-6400* • *KANSAS CITY 2, MO.: 406 W. 34th St., JEfferson 4382* • *LOS ANGELES 23: 3138 E. Olympic Blvd., ANgelus 9-9431* • *TORONTO 9, ONTARIO: 617 Runnymede Rd., Lyndhurst 1654* • *Representatives in Other Principal Cities*

New E-I Frequency Counter has *true* digital in-line read-out!

Here's the answer to your need for an accurate, easy-to-use, events-per-unit-time meter. No other counter has so many convenient features, or is so easy to read. Even the most inexperienced personnel can become proficient in its use *in just seconds!* Human error and reading ambiguities are virtually eliminated.

Important new features found on no other counter!

Easy-to-read digital in-line read-out—Gives readings in simplest possible form. Eliminates reading errors.

Constant reading during sampling—Reads out instantly at end of sampling. No lost readings. No hold adjustments. No annoying sampling changes or "dead-times."

Decimal coded contacts give simple, direct, print out. No intermediate equipment required. No "dead-time" during print out. Operates all types of printers.

Read-out may be remoted and miniaturized—If space is restricted or if used in console-type equipment, the read-out and controls may be remoted on a standard 1¾" rack panel. ½" and 1" high numerals are available.

SPECIFICATIONS—MODEL 250

In-Line Events-per-unit-time Meter and Counter.

Display: 5 in-line digits, 1" high numerals. Display held constant during sampling cycle.

Accuracy: ±1 digit

Frequency Response: 10 cycles to 100 kc

Sensitivity: 0.2 volts rms

Input Impedance: 10 megohms

Time Base: 1 second, crystal controlled. (0.1 and 10 seconds optional)

Controls: Power on-off, sensitivity, re-cycle time, manual time base, manual reset button.

Printer Operation and Remote Read-Out: Optional

Power: 115 volt, 60 cycle

Mounting: Rack or bench

Other standard models and Timers, Universal Counter-Timers available.

E-I "CLOSES THE LOOP"

Now, by adding digital, in-line frequency counters to the E-I line of digital instruments, we are able to offer complete system engineering and system solution. Your phone call or letter will start our engineers thinking about *your* problem.

Automatic, single package, precision instrumentation custom engineered to your system requirements

Fundamental Parameters	E-I Instruments	
DC AC Ω f	DC Digital Voltmeters AC-DC Digital Voltmeters Digital Ohmmeter AC-DC-Ω Digital testers Digital Frequency counters X-Y Recorders	Automatically gives digitized data in both visual and printed form

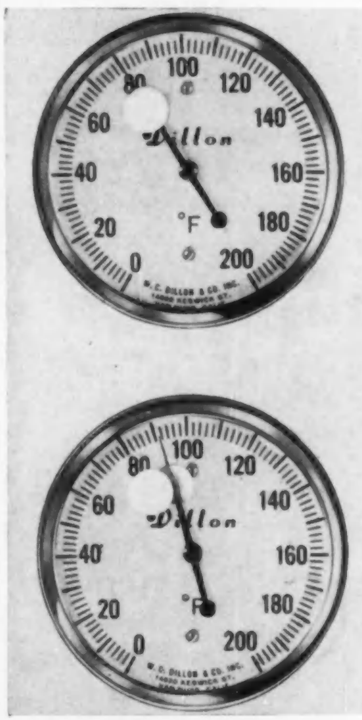
Your E-I representative has complete information on all models and how they can be applied to your counting problems. Contact him today.

ELECTRO INSTRUMENTS INC.

3794 Rosecrans Street, San Diego 10, California

dom voltage whose amplitude probability distribution is gaussian to within one per cent. The output frequency spectrum is flat to within one db from dc to 27 cps in the standard model, but can be modified. A meter indicates the output rms, which is 5 v max. It will be put to work giving computers, simulators, and servo systems a touch of reality. *Automation Laboratories, Inc., Automatic Instrument Div., 517 W. 207th St., New York 34, N. Y.*

Circle No. 18 on reply card



OFF-NORMAL visual indication provided by simple disc.

The scheme above is noteworthy. The dial is of a thermometer, one with a range of up to 1,000 deg F. Fixed with adhesive to the glass dial cover is an opaque white disc. On the pointer of the thermometer is a red disc. White disc is located to cover red at some setpoint. Variations of the pointer expose the red spot, catching the operator's eye. *W. C. Dillon & Co., Inc., P. O. Box 3008, Van Nuys, Calif.*

Circle No. 19 on reply card

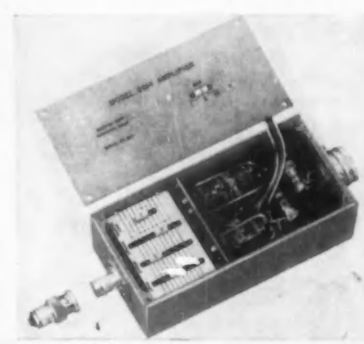
ACCELERATION RECORDER is a magnetic tape machine.

Part of Gulton's group of specialized recording mechanisms is the Model KAT-1, shown above, which is intended for the magnetic tape recording of accelerations up to 60 g. Able to play back for periods up to 30 sec, its output can be visualized by a standard galvanometer, oscilloscope, or direct-writing recorder. *Gulton Mfg. Corp., Metuchen, N. J.*

Circle No. 20 on reply card

FLOW METER: A device just a little larger than an elbow fits in a piping system and indicates by a dial the flow rate through the range of 7 to 70 gph. It contains only one moving part and is said to be accurate to within 2 per cent. *Revere Corp. of America, Wallingford, Conn.*

Circle No. 21 on reply card

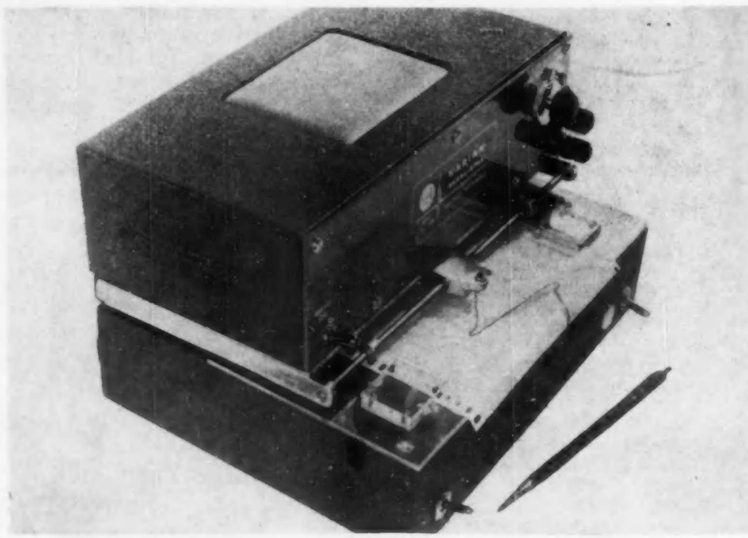


MATCHES PICKUPS to meters for direct-reading ease.

This little preamplifier's function is the happy mating of piezoelectric pickups with vacuum tube voltmeters. That is, the output of the pickup can be trimmed to enable a conventional vtvm to indicate in the desired physical units (i.e., force, acceleration,

pressure, etc.). The Model 2614 amplifier has a selector switch for 3 input impedances and a 3-decade shunt capacitance switch cutting in up to 9,990 mmf. Amplifier gains of 1, 3, and 10 with stability of 10 per cent or better and a frequency response of from 2 to 15,000 cps, with an output of 5 v into 2,500 ohms, are some of its other characteristics. Endevco Corp., 689 S. Fair Oaks Ave., Pasadena 2, Calif.

Circle No. 22 on reply card



LOW COST is big feature of new graphic recorder.

Substantial performance figures accompany the Varian G-10 despite its $279 price. The 15-lb instrument moves its pen full scale in 2.5 sec upon receipt of a 100 mv input. Maximum source resistance is 0.5 megohms for an accuracy of 1 per cent. This self-balancing potentiometer type recorder fits a case about the size of a portable typewriter. *Varian Associates, Special Products Div., 611 Hansen Way, Palo Alto, Calif.*

Circle No. 23 on reply card

PULSES AND DIGITS

DIGITAL VOLTMETER employs Thomson-Varley principle.

This digital voltmeter has 1,000 discrete balance positions and is sensitive to a 10 millivolts full range scale. It attains balance in a maximum of 0.8 sec. The output can operate punched card machines, automatic typewriters, etc. *Consolidated Engineering Corp., 300 N. Sierra Madre Villa, Pasadena 15, Calif.*

Circle No. 24 on reply card

12 ELEMENT GLOW TUBE: A new cold cathode counting tube features 12 cathodes radially spaced around the central anode. The glow on a cathode makes that cathode positive with respect to the other cathodes. Thus a positive voltage is available at any selected count. *Atomic Instrument Co., 84 Massachusetts Ave., Cambridge 39, Mass.*

Circle No. 25 on reply card

RATIOS VOLTAGE DIGITALLY: The ratio between two related dc voltages is indicated in three-numeral form by the Model 625 Digital Ratiometer. Loading of the test circuit by the indicator is less than 0.01 milliamp at worst, and zero when the bridge is balanced. *Hycon Mfg. Co., 365 S. Arroyo Parkway, Pasadena, Calif.*

Circle No. 26 on reply card

ELECTRONIC COUNTERS: Two new electronic counters are now in the production stage, says the maker. Both have four decades, but one has preset features, while the other is extremely small and compact. Input signals of 50 mv are counted at a top speed of 5,000 cps. *Westport Electric, 149 Lomita St., El Segundo, Calif.*

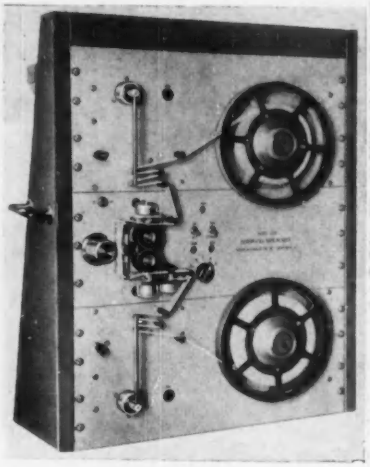
Circle No. 27 on reply card

AN-DIG converter detects rotation through induction.

The little machine shown above will convert a shaft position into any digital code. It can divide one rotation of the input shaft into 4,096 parts. It has no gears or commutators, and operates with shafts turning at up to 240 rpm. Shaft motion is inductively detected. A command pulse initiates a shaft position readout. The output count is an exact measure of the shaft position at the instant of the command pulse. Readouts can be made at up to 20 readings per sec. The converter's shaft inertia is 0.9 oz-in. A complete discussion of the construction and operation of this interesting device appeared in a CONTROL ENGINEERING Idea at Work, November 1954, page 54. *The Austin Co., Special Devices Div., 76 Ninth Ave., New York 11, N. Y.*

Circle No. 28 on reply card

NEW PRODUCTS



PERFORATED TAPE reader uses light to spot holes.

The perforated tape reader above starts and stops in 5 millisec, handles tape speeds up to 60 in. per sec, and reads characters at up to 600 per sec. Model 903 will actually stop on the character in question at speeds up to 150 and 300 per sec and on the character following the one in question at speeds up to 600 per sec. The maker offers similar machines for tape widths of from 11/16 to 1 in. The readout mechanism uses photo diodes. The real size capacity of the machine is 1,000 ft. *Potter Instrument Co., Inc., 115 Cutter Mill Road, Great Neck, N. Y.*

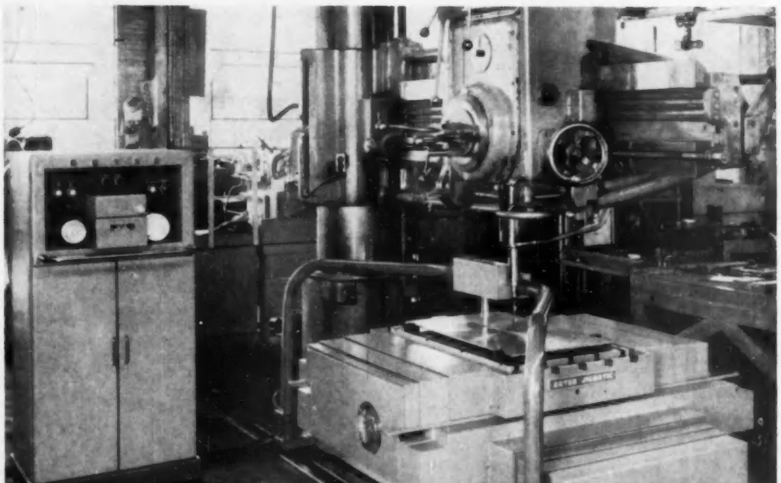
Circle No. 29 on reply card

ELECTRO-MECHANICAL COUNTER: A five-digit counter, known as the Type E-RSA-200, occupies only a little more panel space than its visible numerals require. The counters are tested for 20 cps operation. *North Electric Co., Galion, Ohio.*

Circle No. 30 on reply card

PLUG-IN DECADE: A recently developed package, the size of a sardine can, delivers a stairstep output voltage in ratio to count as well as count indication on an EIT counter tube. Three species of the plug-in style assembly are on hand with top counting rates as high as 250 kc. They all deliver and require 15-v signals. Power requirements are 6.3 and 275 v. *Ransom Research, P. O. Box 382, San Pedro, Calif.*

Circle No. 31 on reply card



ELECTRONIC DRILL JIG uses punched tape control.

The above machine, entirely controlled by punched tape, sets up work for a drill. Positioning time is said to be cut by 600 per cent. The punched tapes, prepared from engineering drawings, limit operators' duties to placing the work properly in the initial position on the table, feeding the tape to the reader, and lowering the drill. The Jigmatic is adaptable to all 4-ft or larger radial drills, says the maker. *Michael Kraft & Co., Inc., 29 Pearl St., Worcester, Mass.*

Circle No. 32 on reply card

DIGITAL VOLTMETER uses two cells to achieve accuracy.

The AC Auto Count, Model 419, is basically a low-level, high impedance digital voltmeter with a range of 0 to 100 millivolts, dc. Its accuracy is 0.1 per cent. Plug-in multipliers extend its voltage range to 1 to 1,000 v, and plug-in shunts give it a current range of from 0.001 to 10 amps. Essentially a self-balancing pot, with the drive turning a mechanical counter, the Auto Count is distinguished by a unique standardization arrangement: a penlight cell is used as the standard voltage source until precise calibration is desired. Then, a "std" button is depressed, bringing into play a standard cell, which automatically sets a trimming pot to correct the error in the penlight cell. In this way, the penlight cell is periodically "zeroed" to a high degree of accuracy. *General Motors Corp., AC Spark Plug Div., Milwaukee 2, Wis.*

Circle No. 33 on reply card

PULSE GENERATOR: This generator fires away at its 400 cps line frequency with saturable reactors instead of tubes. About the size of two cigarette packs, it converts a 275-v pulse into 500 ohms with a rise time of one microsec for 20 to 80 per cent of final amplitude. *Magnetic Research Corp., 200-202 Center St., El Segundo, Calif.*

Circle No. 34 on reply card

CONVERTS FOR IBM: A combination 100-kc electronic counter and IBM punch converter provides count information in visual or punched card form. *Harper Engineering Co., 2330 Michigan Ave., Santa Monica, Calif.*

Circle No. 35 on reply card

DIGITAL OHMMETER shifts its own decimal point.

It takes an average of 1 sec for this machine to display a 4-digit readout of resistances up to 1 megohm. The device uses a stepping-switch self-balancing pot arrangement, which seems to be popular these days. The maker has complete literature. *Electro Instruments, Inc., 3794 Rosecrans St., San Diego 10, Calif.*

Circle No. **36** on reply card

RATEMETER: Two 100 kc counters, one for time and the other for input signals, provide rate information. *North American Philips Co., Inc., 750 S. Fulton Ave., Mount Vernon, N. Y.*

Circle No. **37** on reply card

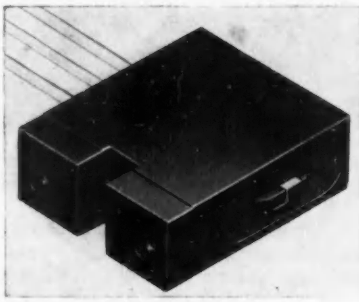
HERE'S A COMPLETE and economical pulse amplifier.

Pulses at high power levels, with many different characteristics of duration, duty ratio, and impedance level, can be handled by the Type 1219-A Unit Pulse Amplifier. It can produce pulses with magnitudes ranging from 600 to 200 milliamp. A 10 per cent droop in the ramp-off passes along a pulse duration of 10,000 microsec. The input impedance is about 50 kilohms shunted by 30 mmf. Its price is $175. *General Radio Co., 275 Massachusetts Ave., Cambridge 39, Mass.*

Circle No. **38** on reply card

MAGNESIUM WAVEGUIDES: Straight, curved, and odd-shaped waveguides of magnesium, including E and H bends, twists, and lengths of up to 10 ft, as well as special magnesium fittings, are part of a line by *Model Engineering & Mfg., Inc., 63 Frederick St., Huntington, Ind.*

Circle No. 39 on reply card



MAGNETIC DRUM heads feature low operating current.

Model MH 10-A, the latest in a series of magnetic drum read and record heads, features an unusually low writing speed, less than 20 milliamps. The readback voltage is better than 0.5 peak to peak. It has 250 turns on each side of the center tap and a gap width of 0.001 in., with resonant frequency of over 500 kc. *Librascope, Inc., 808 Western Ave., Glendale, Calif.*

Circle No. 40 on reply card

KEYBOARD PUNCHED TAPE: A conversion arrangement allows a standard 8 or 10 column adding machine to perforate tape at a rate of 20 characters per sec. The machine performs all its normal calculating functions. The punch is about the same size as the calculator, which is of the standard desk variety. *Clary Corp., Electronics Div., San Gabriel, Calif.*

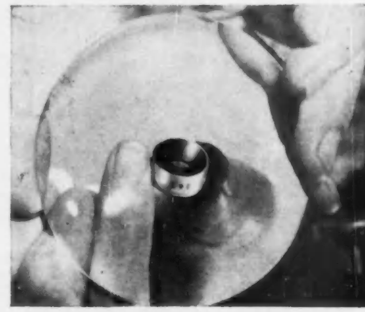
Circle No. 41 on reply card

FEEDBACK FACT

Posed: How to measure photo emulsion thickness without fogging.

Solved: Armour Research Foundation suggests goging by beta rays from a radioisotope.

SENSORS



INFRARED PICKUPS respond in 2 millisec.

These optitherm thermistor detectors, for use in radiometers, pyrometers, and other infrared instruments, contain two sensitive elements: one for measurement of the radiating surface, and the other for ambient temperature compensation. The detectors are hermetically sealed and available with standard silver chloride or KRS-5 windows. *Barnes Engineering Co., 30 Commerce Road, Stamford, Conn.*

Circle No. 42 on reply card

PRESSURE TRANSMITTER: Model 45154 S will meet all performance requirements while subject to a sinusoidal vibration of 25 g at frequencies up to 2,000 cps. The plum-sized pickup has ranges up to 20 psi, absolute, differential, or gage, with accuracy limited only by the resolution of the resistance winding (230 turns). *G. M. Giannini & Co., Inc., 918 E. Green St., Pasadena 1, Calif.*

Circle No. 43 on reply card

ECONOMICAL THERMOSTATS: Field adjustment of set point is a feature in a new line of low-cost thermostats of the snap action variety. Three temperature ranges are available: 50 to 300 deg F, 0 to 250 deg F, and minus 50 to 200 deg F. Six switch types, with protection against expansion element overtravel, increase versatility. *Fenwal Inc., Ashland, Mass.*

Circle No. 44 on reply card

FAST LITTLE SOLENOID: A miniature solenoid recently marketed re-

quires only 5 millisec for coil saturation, the maker says. Through a wide temperature range the work solenoid, 1 in. long and 0.1 lb, pulls 0.5 lb for 0.07 in. Its coil is for 28 vdc. *Carruthers & Fernandez, Inc.*, 1501 *Colorado, Santa Monica, Calif.*

Circle No. 45 on reply card

ELECTRONIC THERMOSTAT: Accurate to half a hundreth of a degree, a new thermostat offers possibilities for pinning down the thermal environment of quartz crystals, transistors, resistors, or other items where temperature plays an important role. *Resdel Engineering Corp.*, 330 *S. Fair Oaks Ave., Pasadena* 1, *Calif.*

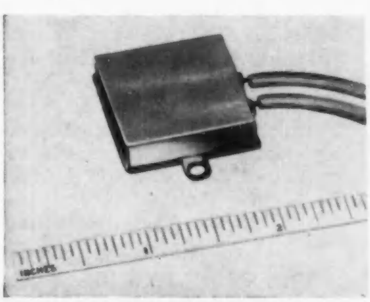
Circle No. 46 on reply card

VACUUM GAGE: Said to be the first hot-wire ionization gage that can be operated at atmospheric pressures, the VEECO Type RG-75 will make measurements below 10^{-8} mm Hg. The thoria-coated iridium ribbon can be exposed to air several hundreds of times without damage. *Vacuum Electronic Engineering Co.*, 86-E *Denton Ave., New York City.*

Circle No. 47 on reply card

TEMPERATURE GRADIENTS SENSED: By means of a group of small, fast-acting thermocouple wells in a single vessel wall entrance, a new Conax Multiple Speedwell gives information on temperature gradients. Temperatures sensed range from minus 300 to 2,000 deg F in systems under pressures up to 3,000 psi. *Conax Corp.*, 7811 *Sheridan Dr., Buffalo* 21, *N. Y.*

Circle No. 48 on reply card



COIN-SIZED thermal switch senses skin changes.

The above hermetically sealed thermal switch uses a bimetal element and stainless steel case. It is designed for mounting on flat surfaces or wher-

ever skin temperature control is wanted. The little mechanism, only 1 in. sq. and ¼ in. high, is factory set for a range of minus 20 to plus 600 deg F. *Control Products, Inc., Sussex St., Harrison, N. J.*

Circle No. 49 on reply card

SEALED voltage protector has thermal element.

Operating in a way roughly analogous to a fluorescent light starter or a thermal time delay relay is this new overvoltage control, which is sensitive to line changes of only 1.3 of standard. Its thermal delay action prevents actuation on sudden peaks, and its construction is said to immunize it against mounting position, acceleration, or vibration up to 500 cps. The device is intended to be used with a transformer and power control relay. Its contacts are limited to 0.5 amps at 28 v. When ac-operated, it is said to have advantages over air-damped relays. Reset time is 10 sec and temperature range is minus 55 to plus 120 deg C. *Jack & Heintz, Inc., Cleveland 1, Ohio.*

Circle No. 50 on reply card

SURFACE SORTER: A contact meter and an electronic roughness gage equip a new surface-roughness inspection tool to automatically sort out parts chuted into it according to a minimum standard of acceptability. *Micrometrical Mfg. Co., 345 S. Main St., Ann Arbor, Mich.*

Circle No. 51 on reply card

LOW-PRESSURE PICKUP: A new pressure pickup for gage or differential ranges of from 0.0 to 0.05 or to 1.0 psi uses a strain-sensitive resistance bridge to produce accuracies of better than half of one per cent. *Dynamic Instrument Co., Inc., 28 Carleton St., Cambridge, Mass.*

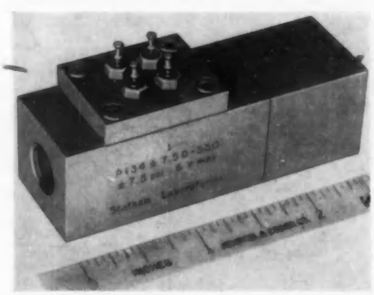
Circle No. 52 on reply card

GERMANIUM AND SILICON LENSES: Because of their high refractive indices, germanium and silicon lenses for infrared use have much less aberration than glass lenses of equal power. The sharp cut-off filter properties of these materials are illustrated by germanium's transparency of beyond 1.8 microns and by silicon's beyond 1.1 microns. They can be anti-reflection coated to transmit more than 90 per cent of the spectral region of interest. *Baird Associates, Inc., 33 University Rd., Cambridge 38, Mass.*

Circle No. 53 on reply card

LOAD TRANSDUCERS: Daytronic's line of transducers for measuring force, weight, and stress has been extended to include the Series 140, which has a full scale range of from 5 to 100,000 lb. These differential transformer type devices are linear to within 1 per cent. *Daytronic Corp., 216 S. Main St., Dayton 2, Ohio*

Circle No. 54 on reply card



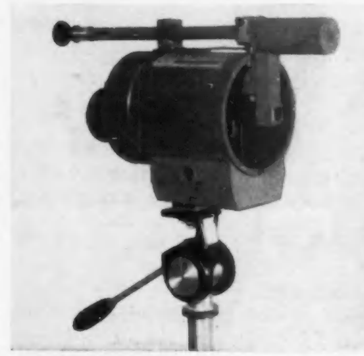
DIFFERENTIAL PRESSURE PICKUPS: Line pressures of up to 250 psig are sensed by strain gages in a new transducer. Pressures from plus or minus 2.5 to 25, from 0 to 5, and from 0 to 150 psid are the normal ranges. High natural frequency and relative insensitivity to acceleration are associated advantages. *Statham Laboratories, 12401 W. Olympic Blvd., Los Angeles 64, Calif.*

Circle No. 55 on reply card

SURFACE PYROMETER: Temperature readings accurate to 0.5 per cent for a range of from 100 to 2,400 deg F are claimed for the Land Surface Pyrometer. A millivolt meter calibrated in degrees allows readings without external power supplies. *Robertshaw-Fulton Controls Co., Fielden Instruments Div., 2920 N. Fourth St., Philadelphia 33, Pa.*

Circle No. 56 on reply card

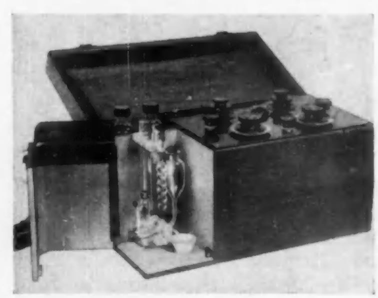
NEW PRODUCTS



PYROMETER works where line of sight exists to heat source.

Variations as small as 0.1 deg. F are sensed by this infrared radiation pyrometer, whose response times are better than 25 millisec and ambient temperature range is to 1,000 deg C. The maker suggests it for situations in which the source of radiation is at a temperature near ambient. Control by pyrometer output has the unique feature of temperature measurement without contact. In some situations this can mean a substantial distance between instrument and material measured. *Servo Corp. of America, 20-20 Jericho Turnpike, New Hyde Park, L. I.*

Circle No. 57 on reply card



pH METER zeroes on null through electron-ray tube.

Unique features of the above instrument include the substitution of an electron-ray tube for a sensitive galvanometer. Narrowing the width of the beam on the screen of the tube indicates a condition of balance. Sensitivities of 0.005 pH are then attainable. Range is from 0 to 14 pH. The instrument can be used as a millivoltmeter, its mv range being 0 to 1,200 millivolts. A weston cell is used as a standard in the potentiometer circuit. *Cambridge Instrument Co., 3732 Grand Central Terminal, New York, N. Y.*

Circle No. 58 on reply card

POTENTIOMETERS

SMALL GANGED POTS: The 500 Acepot, a wire-wound pot ½ in. in diam, is now being made in ganged assemblies. Standard accuracy of linear units is within 0.3 per cent. Torque of the tiny device is 0.035 oz-in. *Ace Electronics Associates, 125 Rogers Ave., Somerville 44, Mass.*

Circle No. 59 on reply card

NEW WAY to make a pot gives direct digital reading.

The "Ta'pot" is a straight slide-wire, direct-reading potentiometer. Non-linear functions are accommodated by variations in the printed calibrations rather than through modification of the resistance element itself. Inside the 144-in., laboratory-type pot is a vulcanized white fibre tape with a resistance element bonded to the edge. Calibration follows assembly. It will handle 2 watts with an accuracy within 0.1 per cent. Available resistance ranges are from 75 to 30,000 ohms. *Howell Instrument Co., 1106 Norwood, Fort Worth 7, Tex.*

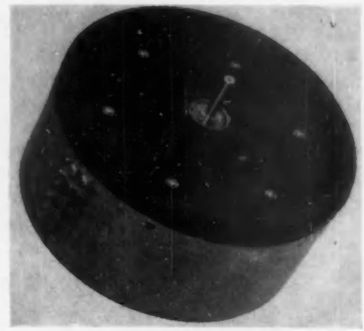
Circle No. 60 on reply card

RESISTANCE DECADE uses plugs instead of switches.

Plugs instead of rotary switches comprise a distinguishing feature of the Vari-plug Resistance Decade. The nominal power rating of the individual resistance is ½ watt. The epoxy-resin encapsulated device contains a thermometer well for checking temperature rise. Two models are stocked, one ranging from 1 to 1,099,999 ohms in 1-ohm steps, and the other from 0.1 to 160,000 ohms in 0.1-ohm steps. Temperature coefficient is 20 ppm per deg C. *Consolidated Resistance Co. of America, Inc., 44 Prospect St., Yonkers, N. Y.*

Circle No. 61 on reply card

NEW PRODUCTS



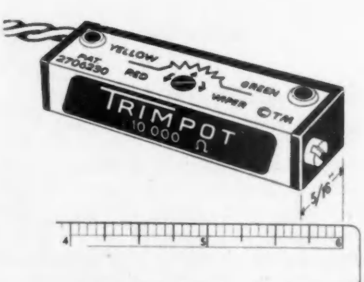
SUPER POT provides super accuracy as a standard.

This instrument is said to be the most accurate potentiometer produced in this country. It is intended for use as a standard. Its linearity is 0.004 per cent, with resolution limited only by the number of turns of resistance wire, which is as high as 106,000. The 10-in. diam device will dissipate 20 watts and is supplied with resistance ranges of from 5 to 200 thousand ohms. *Analogue Controls, Inc., 37 W. 20th St., New York 10, N. Y.*

Circle No. 62 on reply card

GANGING POTS: A new series, C-158, of 1⅝ diam pots features precision construction, either threaded bushing or servo-mounting, and ganged assembly. *DeJUR Amsco Corp., Electronic Sales Div., 45-01 Northern Blvd., Long Island City 1, N. Y.*

Circle No. 63 on reply card



NEW TEMPERATURE range offered with compact trimmer.

Subminiature trimming resistor Model 160, above, adjusts through 25 turns of its adjustment screw. Resolution is 0.25 per cent. Resistance elements, ranging from 10 to 10,000 ohms, handle 0.6 watts. Although

structurally identical to previous models, new high temperature materials provide a minus 65 to plus 350 deg F range. *Bourns Laboratories, 6135 Magnolia Ave., Riverside, Calif.*

Circle No. 64 on reply card

PRECISION voltage-changer combined pot and autotrans.

The Vernistat consists of a tapped autotransformer, which provides the basic division of voltage into several discrete levels, and a continuous one-turn potentiometer, which interpolates these voltages. Tapped portions of the pot are switched sequentially between taps of the autotransformer. By synchronizing the switching with the movement of the potentiometer wiping arm, the voltage of the wiper is varied smoothly through the entire range of voltage provided by the auto transformer.

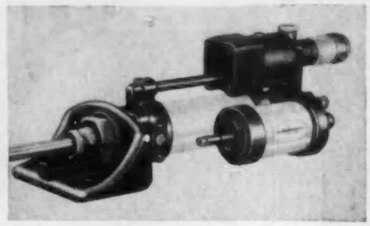
The 400 cycle model shown here has a low output impedance—less than 130 ohms—which eliminates the need for isolation amplifiers in many applications. It also has a phase shift less than many multi-turn potentiometers, says the maker. Size and mounting specifications are those of a size 18 synchro. Its 0.05 per cent linearity suggests possible use as a precision voltage divider. *The Perkin-Elmer Corp., Norwalk, Conn.*

Circle No. 65 on reply card

LINEAL ACTUATORS

OIL-FREE AIR PUMP: An output of 20 psi, automatically regulated, is attained by Model RG-10470 with a completely oil-free impeller and without shaft packing or seals. Capacity of 550 cipm is attained through a $\frac{1}{15}$ hp motor. *Lear, Inc. Lear-Romec Div., Elyria, Ohio.*

Circle No. 66 on reply card



MACHINE FEED is precisely limited by hydraulic resistor.

The function of the machine above is precise control of feed rate from zero to the normal velocity of the controlled machine element. Primarily for use with the maker's air motors, the DCP-50A features automatic flow and thermal compensation. A liquid-filled metallic bellows constantly corrects the flow control valve for changes in hydraulic oil temperature. Stroke lengths from 2 to 18 in. are available. Control may be forward, retract, or both. *The Bellows Co., Akron, Ohio.*

Circle No. 67 on reply card

NEW COMPRESSOR LINE: Stationary compressors in 50, 75, and 100 hp sizes with outputs of 260, 415 and 550 cfm at 125 psi, have been added to a new "S" line by *Le Roi Div. of Westinghouse Air Brake Co., 1706 S. 68th St., Milwaukee, Wis.*

Circle No. 68 on reply card

SEMI-REGULATED: Although it dispenses with magnetic amplifier circuits or vacuum tubes, the ELG line of semi-regulated supplies relies on "stiff" transformers and filters to produce regulation against line and load variations better than 1 per cent, with less than 0.1 per cent rms ripple. Output is in the 200 watt range. *NJE Corp., 345 Carnegie Ave., Kenilworth, N. J.*

Circle No. 69 on reply card

SMALL PISTON PUMPS: Radical design is responsible for the series 65 piston-type pump's performance. The 0.5 gpm machine weighs less than 2 lb and operates at 10,000 rpm. Both constant and variable delivery models are available. *The New York Air Brake Co., Watertown, N. Y.*

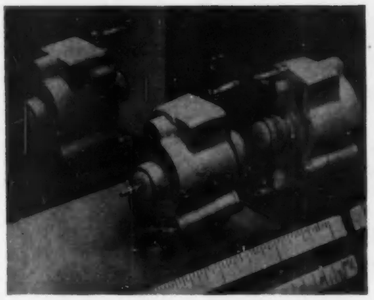
Circle No. 70 on reply card

TORQUE MOTOR pushes mightily despite tiny size.

A mere 40 ma differential current, which could come from a pair of miniature output tubes in push-pull, will provide this neat machine with a full 9-lb force. It can be supplied with low impedance coils for magnetic amplifier operation as well. The plus or minus 0.015 stroke is accurately proportional to input differential current. Full stroke sensitivity is 20 ma. It weighs only 18 oz and is made to ignore large lateral accelerations. Its temperature range is from minus 65 to plus 400 deg C. *Raymond Atchley, Inc., 2340 Sawtelle Blvd., Los Angeles 64, Calif.*

Circle No. 71 on reply card

TORQUE SOURCES



GOVERNED DC motor suitable for tape drives.

Containing a governor which, it is claimed, is not power dissipating, the above 3-oz motor regulates a currently marketed phono turntable to within 1 per cent from idling through full load and over a range of battery voltages from 6.4 to 4.6 v, drawing about 40 milliamps. Its operating speed is 1,800 rpm and its size is $1\frac{3}{8}$ by $1\frac{3}{4}$ by $1\frac{1}{8}$ in. *The Kinder Co., Box 686, South Milwaukee, Wisconsin.*

Circle No. 72 on reply card

RERATED MOTORS: With ratings of from 1 to 30 hp, more power can be jammed in less space in a new line featuring face-type mounting. *U.S. Electrical Motors, Inc., Box 2058, Los Angeles 54, Calif.*

Circle No. 73 on reply card

BRAKE MOTOR: A new line, available in ratings from 1/30 to $\frac{1}{4}$ hp, offers speeds of 5,600, 7,500 or 11,300 rpm. The $5\frac{3}{4}$ in. long motor, for 400 cps 200 v 3-phase systems, can be stopped in less than 1/5th sec. *Westinghouse Electric Corp., Small Motor Div., Lima, Ohio.*

Circle No. 74 on reply card

FLAT MOTORS: A new motor, about half as long as it is wide, has been announced by Diehl. The new power plant is said to be suited for those machine-tool applications that require little space. *Diehl Mfg. Co., Somerville, N.J.*

Circle No. 75 on reply card

NEW PRODUCTS

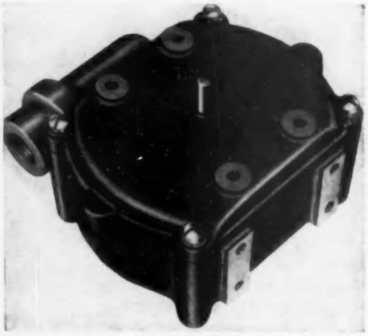
MINIATURE CLUTCHES are not shy of torque.

The apricot-sized device above has several other features besides small size. It has a residual torque when de-energized of only 8 per cent, and can be energized continuously. Coils can be furnished for almost any voltage. *Dial Products Co., 7 Bergen Court, Bayonne, N. J.*

Characteristics

Static torque	7 lb-in.
Weight	0.34 lb
Speed, max.	4,000 rpm
Response time	10 ms
Inertia of driven end	0.01 ft-lb
Power consumption	3 watts

Circle No. 76 on reply card



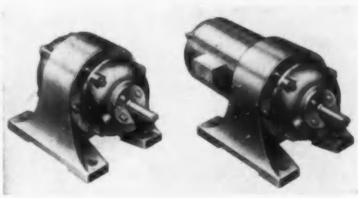
ROTARY SOLENOID specializes in ac applications.

A new line of eight vari-sized rotary solenoids, designed for ac use, offers fractional pound-inch to 63 lb-in. torque in continuous duty models. Intermittent duty machines give proportionally more vigorous twists. Any angle of rotation up to 60 deg can be supplied although 20, 30, and 45 deg are standard. *Lee Spring Co., Inc., Leetronics Div., Dept. 28, 30 Main St., Brooklyn, N. Y.*

Circle No. 77 on reply card

SMALL GEAR MOTOR: Shaft speeds of 3 to 15 rpm are the output of a 662 to 1 gear train, powered by a tiny, dry-cell electric motor in an assembly the size of a cigarette package. *Wilson's of Cleveland, 425 Lakeside Ave., N. W., Cleveland 13, Ohio.*

Circle No. 78 on reply card



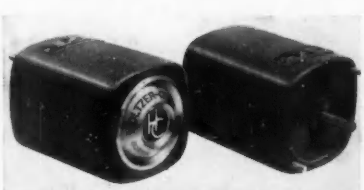
VARIABLE SPEED from ac motors through induction use.

Coupling ac motors to their loads by induction is the business of the MIC drive. Constant torque, plus speed variable from 2 to 1 to 34 to 1, are possible. Motor sizes start at ¾ hp at 3,400 rpm and extend to 75 hp at 1,700 rpm. This coupling can be used to maintain high speed accuracy in closed-loop systems. *American Electric Motors, Inc., 2112 Chico Ave., El Monte, Calif.*

Circle No. 79 on reply card

TOTALLY ENCLOSED MOTORS: Century announces its line of totally-enclosed, fan-cooled motors, from ½ to 100 hp, for both single and polyphase operation. *Century Electric Co., 1806 Pine St., St. Louis, Mo.*

Circle No. 80 on reply card



STYLED FRAMES among the features of low hp line.

Sporting styled frames, a new group of subfractional hp motors is said to have efficiencies of better than 30 per cent—good for their size. Either sleeve or ball bearings can be obtained with the new group. Synchronous and induction models are available from 1/60 to 1/200 hp, and in speeds from 1,700 rpm to 3,400 rpm. *National Pneumatic Co., Inc., Holtzer-Cabot Motor Div., 125 Armory St., Boston, Mass.*

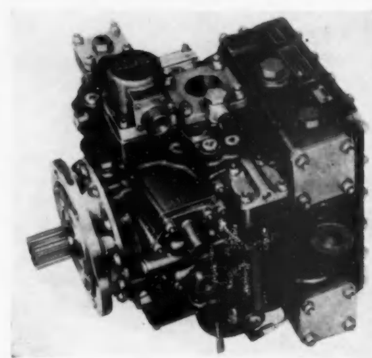
Circle No. 81 on reply card

NEW PRODUCTS

SERVO COMPONENTS

STEPPING SERVO: A recently marketed servo turns its output shaft at speeds up to 1 rps in 8, 10, 12, 18, 24, or more steps. Input signal is 1 v per step and the output shaft torque is approximately 1.5 lb-in. The input impedance is 1 megohm. *Bergen Laboratories, 11 Godwin Ave., Fair Lawn, N. J.*

Circle No. 82 on reply card



SERVO pump converts small signals to massive motions.

The PV 3918, a new 3,000 psi aircraft-type servo pump for rotary or linear servo applications, delivers 55 hp at 35 gpm. It controls positioning through electronic or magnetic amplifier signals. The pump is generally engineered into systems having an oil cooler, oil reservoir, electric motor, and hydraulic actuator. *Vickers, Inc., Detroit 32, Mich.*

Circle No. 83 on reply card

SERVO MOTOR: Operating temperatures up to 150 deg C are possible with a new size 15 (400 cps) servo motor. 60 cycle operation is also possible with the 115-v. device. *John Oster Mfg. Co., 1 Main St., Racine, Wis.*

Circle No. 84 on reply card

STATIC ELEMENT SERVO AMPLIFIERS: A new line of transistor-magnetic servo amplifiers features static components only. Transmags

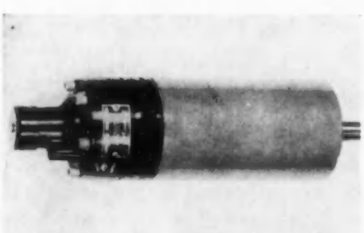
operate on either 60 or 400 cps with an ambient temperature range of from minus 50 to plus 71 deg C. *Magnetic Amplifiers, Inc., 632 Tinton Ave., New York 55, N. Y.*

Circle No. 85 on reply card

HIGH RESPONSE servo valves built to small tolerances.

The servo valves above are said to have a time constant of 1.5 millisec from input differential current to output flow. Maximum output is 9 gpm in systems under 500 to 3,000 psi pressure. Full flow is obtained with a current differential of only 8 ma max. The valves use a floating armature between two nozzles. Bronze 5 micron filters take care of dirt. Internal clearances are said to be on the order of millionths of an inch in spots. *Bendix Aviation Corp., Pacific Div., 11600 Sherman Way, North Hollywood, Calif.*

Circle No. 86 on reply card

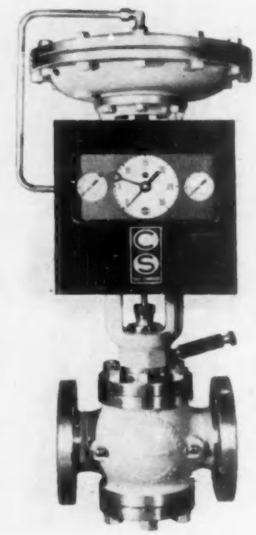


PNEUMATIC SERVO is a smaller linear actuator.

The model B-50 Conomotor is a smaller version of the maker's pneumatically positioned power operators. The new item can produce a stroke of 2 in. with a thrust of 300 lb in either direction. It works with supply pressures of up to 100 psi and with a 3 to 15 psi control signal range. *Conoflow Corp., 2100 Arch St., Philadelphia, 3, Pa.*

Circle No. 87 on reply card

CONTROL VALVES



PILOT CONTROLS temperature as well as pressure.

This new pilot, shown mounted on a control valve, is said to be the first of its kind to regulate temperature as well as pressure. The pilot is applicable to pressure ranges of from 0 to 15 and 0 to 10,000 psi; and of from 0 to 30 in. Hg vacuum. The temperature controller is a mercury-actuated capillary sensing element. The Type 51 pilot has a 1 to 100 per cent proportional band. *A. W. Cash Co., P. O. Box 551, Decatur, Ill.*

Circle No. 88 on reply card

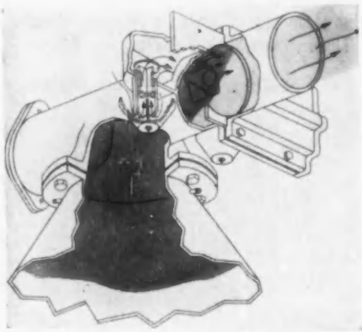
FLOW CONTROLLER: A new power-actuated flow controller with pneumatic, hydraulic, or electric positioning control consists of a venturi metering section, a pressure recovery section, and a power-actuated valve mechanism. Accuracy within plus or minus 3 per cent through the range of 25 to 100 per cent maximum capacity is claimed. *Builders-Providence, Inc., 345 Harris Ave., Providence, R. I.*

Circle No. 89 on reply card

CAM VALVE: A new valve for pneumatic systems with cam-determined air delivery is sealed against dirt or

dust. Three- and four-way $\frac{3}{8}$ in. sizes are made. *Mechanical Air Controls, Inc., 10030 Capital, Oak Park, Detroit 37, Mich.*

Circle No. 90 on reply card



BULK VALVES are self-cleaned to insure tight closure.

A new line of Type C material handling valves with manual, air-electric, or remote controls is specifically designed for systems that move dust, fly ash, or other particles through vacuum piping. Atmospheric air is admitted through inlet ports at rates matched to the increases and decreases of the load on the system. Air-electric units are equipped with air cylinders controlled by three-way solenoid valves. All the valves are of the gate type: they use the system's vacuum to help seating and to keep the gate from jamming. *The Allen-Sherman-Hoff Co., 259 E. Lancaster Ave., Wynnewood, Pa.*

Circle No. 91 on reply card

SWITCHES, RELAYS, AND TIMERS

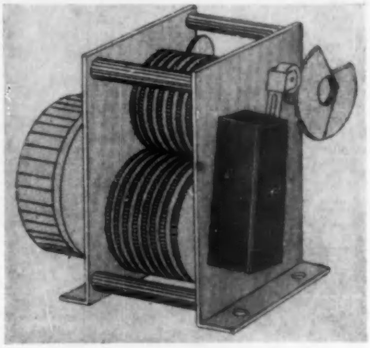
OVERHEAT GUARD fits in motor or transformer winding.

The above miniature overheat pro-

NEW PRODUCTS

tector can be mounted directly in motor or transformer enclosures. The sealed molded phenolic case and snap-action switch element will withstand the rigors of varnish dipping and baking. The B9500 will halt 300 v max. and 10 amp at 115 vac, and is said to be especially suited for split capacitor and shaded pole motors. *Metals & Controls Corp., Spencer Thermostat Div., Attleboro, Mass.*

Circle No. 92 on reply card



TIMER'S RANGE varied by a factor of 40,000.

The little machine above consists of a group of gears driven by a synchronous motor. A cam on the output shaft operates a switch at a rate determined by the selected gear ratio. A 13-step speed range of from 1 sec to 1 month per revolution and output torques of up to 40 oz-in. are available with some models. Most of them change speeds by manual repositioning a gear along their shafts. One model has instant-action gear re-positioning. Prices vary between $17 and $47. *Gorrell & Gorrell, Haworth, N. J.*

Circle No. 93 on reply card

ELECTRONIC RELAY: A heavy-duty device with a capacity of 20 amp at 120 v features a panel-mounted rotary switch for selecting the operating relationship of input to output. *Arthur S. LaPine & Co., 6001 S. Knox Ave., Chicago 29, Ill.*

Circle No. 94 on reply card

LIGHTED PUSH BUTTONS: A new line of pushbutton switches containing integral indicator lights ranges in size from ½ to 1 in. in diam. Switch and light circuits can be fully independent. *Marco Industries Co., 207 S. Helena St., Anaheim, Calif.*

Circle No. 95 on reply card

A NOTE ABOUT ARTICLE REPRINTS

DEAR SUBSCRIBER:

Your request for article reprints has been gratifying because it helps us to know that what we print is on the beam. Still, it has created a problem in handling. So we'd like to establish the following routine.

1. One reprint of an article is free. But please limit requests for single copies of different articles to six.

2. A charge of SIX CENTS PER PAGE will apply for requests of from two to 100 reprints of an article. This just covers our own costs for processing, sorting, and mailing. Multiplying six cents by the number of pages in the article by the number of copies you want gives you the price of your order. Some orders in Category 2 will be filled by tear sheets, but most by black and white but quite serviceable Bruning facsimiles.

3. If you order exceeds 100, you will be advised of several prices—each determined by the method of reproduction you choose. Some articles lend themselves to only one method, and therefore, one price.

Sincerely yours,

THE EDITORS

ORDER FORM FOR REPRINTS*

TO CONTROL ENGINEERING REPRINT SERVICE
330 W. 42 St., N. Y. C.

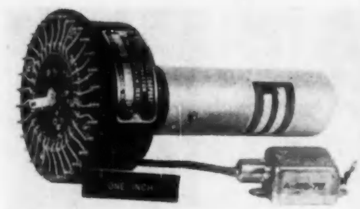
I have enclosed a check for —— to cover the cost of reprints of the following:

Issue	Page	Quantity
1. ..	....	....
2. ..	....	....
3. ..	....	....
4. ..	....	....

*** SINGLE REPRINTS ARE FREE**

Signed ....

Address ....



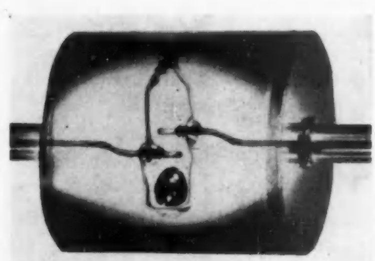
MOTORIZED SAMPLING switch has governed motor.

The sampling switch shown here has two poles of 60 contacts each for a sampling speed of 5 rps. The 28 vdc drive motor has a governor and a line filter. Its service life is over 100 hours. Other models of the AE switch incorporate sampling speeds ranging from 1 to 30 rps and one of a number of contacts, drive motor voltages, poles, and per cent duty cycles. *Applied Science Corp. of Princeton, P. O. Box 44, Princeton, N. J.*

Circle No. 96 on reply card

PLUNGER SWITCH: Actuated by a cam, door, or indexing knob, a new plunger-type switch, about 1 in. in diam, can make or break one or two circuits in sequence, carrying up to 20 amp at 230 vac. *P. R. Mallory & Co., Inc., 3029 E. Washington St., Indianapolis 6, Ind.*

Circle No. 97 on reply card



PULSE SWITCH operates with flying mercury droplet.

This phantom view of a new pulse switch more or less explains its operation: one revolution causes the mercury droplet to momentarily connect the sealed contactors. The maker, which has a line of pulse switches, points out that this item can be used as a governor (at high rpm the droplet will never close the contacts). *Tensitron, Inc., Harvard, Mass.*

Circle No. 98 on reply card

ABSTRACTS

Pulse Rate Plotter

From "Versatile Digital Recorder," Product Engineering, August 1955, p. 143.

An instrument primarily designed to plot pulse rates on graph paper also performs simple calculations. It punches holes or prints points according to Y/X, where both are electrical pulse rates. If Y is a variable rate and X a fixed rate, the machine will plot points indicating the number of Y pulses received between X pulses. A series of these points thereby becomes a graph of the Y pulse rate. If X is a variable rate as well, the graphic output describes the *ratio* of Y/X. The spacing between the printout points can be varied by a third pulse series, so that the instrument can be used to display three pulse rates if required.

Indication of the rates of such events as the operation of a pulse-type pump, of objects passing on a production line, of the rate of operation of an on-off controller, of completed operations at an assembly station, of plant traffic, etc., are typical uses envisioned for the instrument. If the Y rate is a fixed time rate and the X rate becomes the variable measured, the graphic output of the instrument is that of the time between the X pulses. Hence, a graph of the time required to complete an assembly station, to fill a container, between cycles of an on-off controller, etc., can be indicated in graphic form as a function of time. The instrument was developed by Raymond N. Auger, of 552 Riverside Drive, New York 27, N. Y.

Although the Digi-Graph, as the device is called, was designed to accurately display low pulse rates (since its integration is internally accomplished by discrete electro-mechanical actuations) the fact that it counts each pulse equips it for stepping-switch computer circuits. Storage, subtraction, multiplication, division, addition, logarithmic and exponential functions, as well as conversion from binary code to other binary, decimal, or analog values, are relatively easy operations to accurately concoct with stepping-switches.

The article describes the circuit for an integral curve computer. In this circuit two stepping switches and four relays perform integration, multiplica-

tion, addition, and subtraction. When this circuit is teamed with the plotter, any variations from a "set point" pulse rate (which is selected by a rotary switch) can be integrated and graphed. Because of the discrete electromechanical actuations of the instrument's internal operation, it will operate on extremely slow pulse rates with the same accuracy as its maximum input rates.

With other circuits, the device plots the individual rates of a number of different sources sequentially (a monitoring set-up in which one stepping switch selects each different source). About the size of a clarinet case, the Digi-Graph uses a leadscrew for integration, and moves its graph paper in discrete steps. It was developed to graphically indicate and record pulse rates without expensive electronic integration or substantial error due to ambient and aging effects.

Low Expansion Alloys

From "Low-Expansion Cobalt-Iron Chromium Alloys", Summary Technical Report, National Bureau of Standards, U. S. Department of Commerce, Washington 25, D. C., August 1955.

The thermal expansion of certain cobalt-iron-chromium alloys is extremely low and nearly constant between 20 and 60 deg C. This information results from thermal expansion and phase transformation studies on a number of these alloys by Peter Hidnert and Richard K. Kirby at the National Bureau of Standards.

Generally fused quartz, invar, and some ceramics are used in thermostatic and measuring devices where dimensional changes due to changes in temperature must be kept small. But of these materials, only invar is metallic, and it is subject to small but significant dimensional changes over long periods of time.

The bureau's investigation indicates the existence of an alloy (36.6 per cent iron, 8.9 per cent chromium, and the balance cobalt) with a coefficient of expansion less than 1×10^{-6} per deg C for the range from 20 to 60 C. The low expansion of such alloys is, however, very sensitive to small variations in chemical composition. Also, some of them undergo a transformation on cooling at low temperatures.

Measurements were made on 19 samples, each 30 cm long, with iron contents varying from 36.2 to 37.2 per cent and chromium contents varying from 8.6 to 9.9 per cent by weight.

The effects of various heat treatments from minus 196 to plus 1,000 deg C on the phase changes were studied with the aid of micrographs and micrometers and expansion apparatus, the latter measuring the dimensional changes.

Of the samples investigated, those with chromium contents ranging from 8.6 to 9.2 per cent have very low rates of expansion around room temperature. In fact, some of these alloys have coefficients of expansion less than those for fused quartz and ordinary invar between minus 65 and plus 60 deg C. But on cooling, they undergo a first-order transformation of the martensitic type. This results in a low-temperature phase that has a very much higher rate of thermal expansion than the original high-temperature phase, up to 200 deg C. The temperatures at which these transformations start were found to be as high as minus 10 deg C and decreased with increasing chromium content. The change in crystalline phase proceeds with discrete audible clicks and slight increases in temperature. A needle-like martensitic structure is finally produced. The reverse transformation, which reproduces the high temperature phase, starts at about 600 deg C but is not complete until the material is heated above 900 deg C.

Further research is needed to develop additional information on the physical properties of these low-expanding alloys at various temperatures. In this way, the practicability of these alloys in commercial applications—such as the production of fine wire and surveying tape—can be determined.

For Better Digital Storage . . .

From "High-Density Tape Recording for Digital Computers", Summary Technical Report, National Bureau of Standards, U. S. Department of Commerce, Washington 25, D. C., August 1955.

In a series of experiments performed by J. R. Sorrells, both continuous-current and pulse techniques were investigated to achieve densities in the range of 500 to 700 pulses per in. Recording and reading circuitry was also developed to provide large-ampli-

ABSTRACTS

tude playback signals with error-free differentiation between binary *ones* and zeroes.

An integral part of many large high-speed electronic computers is some type of magnetic tape or wire storage system which serves as an input-ouput means, as an external low-speed memory, or in some cases as both. Many mathematical problems require extensive use of an external storage system. In solving some of these problems relatively little actual computation is performed, but a great deal of data must be handled and assimilated by the computer. Ideally, the magnetic tape system would supply or receive data from the machine at a speed that allows the computer to proceed with the problem solution at its normal rate. In reality, however, the maximum rate at which information can be accomodated by the tape unit is usually very slow compared to the speed of the machine because of tape speed limitations and the comparatively low density at which information is commonly stored on the tape. Thus, the majority of problem solution time is spent not in computation, but in the performance of input-output or tape storage operations.

Higher Access Rates

The investigation has been directed toward improving magnetic tape storage techniques to permit more rapid transmission of information to the computer by increasing the number of digital pulses recorded on each inch of the tape, thereby also increasing the overall efficiency of the machine. Tape drive units are already in operation with the NBS electronic computer, SEAC. These provide high-speed starting, stopping, and reversing of the magnetic tapes, together with maximum practical tape speeds.

One variation of the non-return-to-zero (NRZ) system of tape recording was selected for the present investigation. In this system, as ordinarily applied, current sufficient to saturate the tape is maintained in the recording head at all times, but the polarity is changed each time a binary *one* is to be recorded. When a binary zero is to be recorded, the current is not changed. This type of recording produces a single change in magnetic flux on the tape for each binary *one* and no change in flux for a zero, so that on playback a voltage is produced only when a *one* is read. This has disadvantages: a continuous current must be maintained in the head during recording, and the polarity of the current must be switched rapidly. Unless center-tapped head windings are used, rather complicated driver circuits that consume considerable power become necessary. To overcome these drawbacks, the Bureau of Standards used a digital pulse technique instead of the continuous current method to achieve NRZ tape magnetization.

New Pulse Technique

In application, the pulse technique is analogous to the continuous current method. To record a binary one with the pulse technique, a pulse of opposite polarity to the previous pulse is recorded. To record a binary zero, a pulse of the same polarity as the previous one is recorded. Thus on playback, there is a single voltage swing for each recorded *one*, and no voltage for a zero.

To find the maximum usable pulse density, a number of recordings were made on tapes that had previously been erased with alternating current. For each recording the tape speed was held constant, the pulse duration was two microsec, and the pulse current was 60 ma. The only paraeter changed was the pulse repetition rate; this was increased so that for successive recording the pulses were crowded closer and closer together. When the recordings were read back, it was found that the playback voltage increased with pulse density until a maximum of 440 pulses per in. was reached. The voltage then began to decrease for greater densities, but so slowly that even at 730 pulses per in. the output signal amplitude was still usable.

By recording words of information that contain a known number of *ones* and zeroes, it was possible to obtain a fair check of the performance of the system by counting the number of *ones* and zeroes on playback. Without taking any precautions to prevent errors from tape flaws, several runs of one to 3 million digits were recorded and read at densities of 500 to 600 digits per in. without apparent errors.

A sprocket channel is used both to interpret the playback signals and to time the pulses recorded in the information channels. Crosstalk from the large sprocket channel signal is attenuated by a low-pass filter in the sprocket channel amplifier. The sprocket signal is a sharp pulse only two microsec long, while the recorded signal is packets of nearly pure sine waves.

NEW BOOKS

Higgins on an Advanced French Text

Calcul Statistique Des Systemes Asservis (The Statistical Calculation Of Servo Systems), *Marc J. Pelegrin, Aeronautical Military Engineer, French Air Ministry, 156 pp. Publications Scientifiques et Techniques du Ministere de l'Air No. 285. To be purchased from Au Service de Documentation et D'Information Technique de l'Aeronautique, Magasin C.T.O.s 2, Avenue de la Porte-d-Issy, Paris (15°), France, 1,200 francs.*

In the "Introduction" the author states that this book stems from a graduate course he took at MIT under Professor Y. W. Lee on the statistical theory of telecommunications; specifically expositions, extension, and application of Wiener's optimum filter theory. Pelegrin utilizes certain basic aspects of this theory for effecting a statistical analysis and synthesis of servomechanisms, with particular application to autopilot feedback control systems such as the Siemens K12 and kindred autopilots.

The first of the five chapters is a concise account of certain basic aspects of "Servo Systems and Wiener's Theory". The content of this chapter is indicated by the headings of its four sections: 1.1. Transfer functions of a linear system; 1.2. Stability of a servo systems; classical definition, statistical definition; 1.3. Remarks concerning harmonic analysis; 1.4. Brief outline of Wiener's theory.

Chapter II, "Determination of the Transfer Function of a Linear Servo System", in three sections, considers a unity feedback system that makes use of the Wiener theory to minimize the mean-squared-error. The course of analytic procedure first is detailed in general terms and then illustrated through solution of a particular feedback control system—simulating a radar pursuit system. A study of a particular class of nonlinear systems, namely those in which the nonlinear elements are electromagnetic relays, follows.

Chapter III, "A Detailed Study of "Relays", has sections on terminology, action, and principal types and uses of relays; analytic characterization of sign relays and balance relays, and an account of extensive experimentation to ascertain the dispersion in relay time-constants.

Chapter IV, "Procedures and Meth-

NEW BOOKS

ods of Calculation; Remarks on Nonlinear Systems", is in three sections: the first remarks the essential distinction between linear and nonlinear systems; the second outlines determination of the probability functions characterizing the action of a relay as a circuit element, and details some of the main points to be considered in the analysis and synthesis of nonlinear systems by the statistical approach of the text; and the last stresses the necessity of using high-speed autocorrelators for effecting the heavy numerical computation incident to the statistical approach, listing some autocorrelators available in France.

Chapter V, "External Effects—Study of Atmospheric Turbulence", is a detailed account of the physical assumptions and analytic techniques for a statistical characterization of atmospheric turbulence. Such an undesirable force must be encompassed in autopilot-control of high-speed fighter aircraft.

The author remarks in a "Conclusion" that the theory developed in the book enables direct synthesis of the autopilot within the framework developed in the text.

Although published in 1953, the book is still of prime interest. The reviewer recommends a careful reading by all control engineers who have a special interest, or a daily concern, with autopilot or kindred control problems. Chapters I, II, and V are highly mathematical and the associated text is easy to read. The more wordy text of Chapters III, IV, and the introduction has been translated into English—in the monograph, Library Translation No. 475, Royal Aircraft Establishment, Farnsborough, England, July 1954—which can be purchased from the Ministry of Supply, London W. C. 2, England.

. . . on a British Digital Conference . . .

AUTOMATIC DIGITAL COMPUTATION. *Published by Her Majesty's Stationery Office, London, England. 296 pp. 1 pound, 1 shilling.*

This is a reprinting of the proceedings of the third International Conference on Automatic Digital Computing, held at the National Physical Laboratory, England, March 25-28, 1953, and originally issued in 1954. Its republication reflects the current great

For More Information

from ADVERTISERS

FILL IN THIS CARD →

ADVERTISER	PAGE NO.
________________	____
________________	____
________________	____
________________	____
________________	____
________________	____
________________	____
________________	____
________________	____
________________	____

CONTROL ENGINEERING
NOVEMBER 1955

NOT GOOD IF MAILED AFTER JANUARY 1, 1956

NAME ....

POSITION ....

COMPANY ....

ADDRESS ....

CITY and STATE ....

Please type or print plainly

about NEW PRODUCTS

CIRCLE THESE NUMBERS →

to get NEW BULLETINS & CATALOGS

CIRCLE HERE → THE NUMBER YOU SELECT HERE ↓

1	2	3	4	5	6	7	8	9
10	11	12	13	14	15	16	17	18
19	20	21	22	23	24	25	26	27
28	29	30	31	32	33	34	35	36
37	38	39	40	41	42	43	44	45
46	47	48	49	50	51	52	53	54
55	56	57	58	59	60	61	62	63
64	65	66	67	68	69	70	71	72
73	74	75	76	77	78	79	80	81
82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99
100	101	102	103	104	105	106	107	108
109	110	111	112	113	114	115	116	117
118	119	120	121	122	123	124	125	126
127	128	129	130	131	132	133	134	135
136	137	138	139	140	141	142	143	144
145	146	147	148	149	150	151	152	153

CONTROL ENGINEERING
NOVEMBER 1955

NOT GOOD IF MAILED AFTER JANUARY 1, 1956

NAME ....

POSITION ....

COMPANY ....

ADDRESS ....

CITY AND STATE ....

Please type or print plainly

(100) MEASUREMENT, CONTROL. Doelcam Div. of Minneapolis-Honeywell Regulator Co. Folder, 9 pp. Five data sheets cover a magnetic null indicator, an indicating amplifier, a selective range dc amplifier, a position indicator, and a bi-directional pickoff.
(101) SWITCHES. Micro-Switch Div. of Minneapolis-Honeywell Regulator Co. Catalog 83, 28 pp. Covers enclosed switches for many industrial applications. All come in a variety of designs, contact arrangements, and electrical ratings.
(102) DIAPHRAGM CONTROL VALVES. Industrial Div. of Minneapolis-Honeywell Regulator Co. Bulletin, 4 pp. Specifications for double seated, single seated, and three-way valves. Flow characteristics are good.
(103) SPEEDOMAX RECORDER. Leeds & Northrup Co. Data Sheet END46(4), both sides. Any measurement in terms of a dc voltage can be made with this adjustable zero, adjustable range recorder, sensitive to 1/10 of 1 per cent of range span or 3 mv, whichever is larger.
(104) DIGITAL RECORDING. Metrotype Corp. Publication M-55-100, 8 pp. Tells about digital recording that automatically measures and logs with an accuracy of plus or minus $\frac{1}{2}$ per cent and records in $\frac{1}{3}$ sec.
(105) TEMPERATURE CONTROL. Wheelco Instruments Div. of Barber-Colman Co. Bulletin F 5795, one sheet. "Capaciline" device supplements controlled heating equipment by compensating for heat transfer lags. Does not affect reading at control point.
(106) TROUBLESHOOTING PYROMETERS. Wheelco Instruments Div. of Barber-Colman Co. Bulletin F7259, 11 pp. Gives service tips for handling 15 problems that can arise with pyrometers.
(107) VARIABLE SPEED CONTROL. Allis-Chalmers Mfg. Co. Bulletin 51B-8166, 8 pp. Here's a package drive with magnetic amplifier generator field control and motor ratings of 5 to 200 hp.
(108) PERMANENT MAGNET. The Indiana Steel Products Co. Catalog 15, 4 pp. This is a light-weight (0.18 lb per cu in.), low-cost, non-metallic pm made of the new ceramic material, Idox, which is highly resistant to demagnetization. Specs for wafers, cylinders, and rings.
(109) INDOX VS. ALNICO. The Indiana Steel Products Co. "Applied Magnetics", July 1955, 11 pp. Engineer Richard A. Scholten reports in this issue on the relative adaptability to synchronous drive design of Indox and Alnico pm's.
(110) HIGH STABILITY RESISTORS. Pyrofilm Resistor Co. Bulletin. Tells about new glass sealed carbon filled resistors that are stable and small ($\frac{1}{16}$ in. diam. by $\frac{11}{16}$ in. long.
(111) TAPE RECORDING. A-V Mfg. Corp. Bulletin 103, 16 pp. Covers building block components and accessories that make up systems of 2 to 14 channels for recording instrumentation data.
(112) VARIABLE SPEED DRIVES. Sterling Electric Motors, Inc. Bulletin, 8 pp. New information on the Speed-Trol variable speed transmissions includes description of the positive pulley, through which speed settings are positively fixed and immunized against variations in load.
(113) CONTROL VALVE. A. W. Cash Co. Bulletin 966, 4 pp. Describes Types 10 and 10S, two pilot-operated valves that can carry out each other's function when their control lines are switched. Type 10 is designed for pressure reducing and regulating, Type 10S, for back pressure control.

Postage
Will Be Paid
by
Addressee

No
Postage Stamp
Necessary
If Mailed in the
United States

BUSINESS REPLY CARD
First Class Permit No. 64, (Sec. 34.9, P. L. & R.) New York, N. Y.

Reader Service Department

CONTROL ENGINEERING
330 West 42nd Street
New York 36, N. Y.

Postage
Will Be Paid
by
Addressee

No
Postage Stamp
Necessary
If Mailed in the
United States

BUSINESS REPLY CARD
First Class Permit No. 64, (Sec. 34.9, P. L. & R.) New York, N. Y.

Reader Service Department

CONTROL ENGINEERING
330 West 42nd Street
New York 36, N. Y.

(114) TACH GENERATORS. Weston Electrical Instrument Corp. Catalog D9A. Details, bearingless tach generator and describes ac and dc voltage responsive and frequency responsive systems.

(115) RESISTORS. Cinema Engineering Div. of Aerovox Corp. Bulletin LC-1030A, 20 pp. Pocket-sized charts give dimensions, wattages, maximum resistances, and military equivalents for resistors for terminals, and for printed circuitry.

(116) SPEED REDUCERS. Western Gear Corp. Bulletin 5503. Presents data on spiral bevel-helical gear-type units.

(117) INFRARED RADIATION PYROMETERS. Servo Corp. of America. Bulletin TDS-IRPS 655. Tells about two control instruments for temperature measurement without contact. Ranges are 50 to 1,000 deg C and ambient to 1,000 deg C.

(118) COMPUTER COMPONENTS. Servo Corp. of America. Brochure, 12 pp. Covers "Servomation" building blocks for general purpose analog computers. Combinations of modular assemblies control industrial processes, solve mathematical problems, and process data.

(119) pH BUYER'S GUIDE. Beckman Div. of Beckman Instruments, Inc. Bulletin 425, 4 pp. This handy manual for instrument users tells which new components replace older ones, how new and old may be used together.

(120) AF WAVE ANALYZER. Instrument Div. of Federal Telephone & Radio Co. Bulletin 155-234 E, 4 pp. About a new instrument with extreme sensitivity, fast response, and small distortion.

(121) GERMANIUM POWER RECTIFIERS. International Rectifier Corp. Bulletin GPR. Contains operating instructions, dynamic characteristic curves, specifications, and ratings for natural convection cooled and fan cooled rectifiers.

(122) SILICON POWER RECTIFIERS. Automatic Mfg. Corp. Bulletin MP-755, 4 pp. Tells about hermetically sealed, medium power devices that operate at ambient temperatures of minus 55 to plus 155 C. Forward resistance and reverse leakage currents are low, reverse voltages are high.

(123) AN-DIG CONVERTER. J. B. Rea Co. Brochure, 8 pp. Describes the Rea analog-to-digital converter and systems in which it operates. Photographs and block diagrams included.

(124) SLIDE VALVES. Aircraft Products Co. Data Sheet Series 4000, 4 pp. New slide-type sequence valves for 3,000 psi hydraulic service handle temperatures of minus 65 to plus 275 F (standard) and wider for special models.

(125) GEAR CLASSIFIERS. Michigan Tool Co. Bulletin 355, one sheet. Explains how these classifiers automatically monitor gears on production line. Heart of the system is the classifier controller.

(126) SAMA FILM DIRECTORY. Scientific Apparatus Makers Association. Lists all free movie and strip films available through SAMA. Subjects of the 14 motion pictures range from optical instruments to basic electronics.

(127) INLAND TESTING LABS. Brochure, 37 pp. A comprehensive survey of the personnel, equipment, and instrumentation on hand at this relatively new facility. A lot of details on a lot of instruments packed in with many relevant photographs.

(128) ENGINEERING DESIGN. Contract Div. of Electronic Specialty Co. Catalog. Describes sensing devices, timers and time delay relays, flashers, and special aircraft test equipment and miniature components.

(129) RELAYS. Hedin-Tele-Technical Corp. Bulletin. The three new series 100 relays described are said to incorporate sensitivity with a thorough wiping effect. Hermetically sealed and long-lived.

(130) CARBON PRECISTORS. International Resistance Corp. Catalog Data Bulletin B-6a, 4 pp. Contains specs for ½-, 1-, and 2-watt boron carbon precistors.

(131) HIGH VOLTAGE RESISTORS. International Resistance Corp. Catalog Data Bulletin G-1a, 8 pp. Gives the full treatment to Type MV resistors.

(132) CONTROLLABLE INDUCTORS. CGS Laboratories, Inc. Two bulletins, 8 pp. and 16 pp. The first bulletin gives a light but lucid treatment to the "Increductor", a high frequency saturable reactor, while the second gets down to business with data sheets, basic circuit diagrams, and selection tips.

(133) PANORAMIC RECEIVER. CGS Laboratories, Inc. Bulletin, one sheet. Describes the fast, silent, all-electronic TRAK unit that uses "Increductors" to scan the VHF spectrum.

(134) TUNING LOCK. CGS Laboratories, Inc. Bulletin, 4 pp. Covers a TRAK device that automatically compensates for drift.

(135) PATENT PROTECTION. CGS Laboratories, Inc. Booklet, 18 pp. "Preparing for Patent-Hood", by CGS President Elton T. Barrett, presents steps in patent protection.

(136) PROXIMITY METER. Robertshaw-Fulton Controls Co., Fielden Instrument Div. Technical and Application Manual TM-951-1, 28 pp. Describes a non-contacting capacitance gage that measures to a thousandth of a degree C or to a millionth of an inch. Fifteen applications suggested.

interest in digital computing as a tool in all phases of science and engineering.

Included are the opening address by the noted English physicist D. R. Hartree, who spoke on various aspects of digital computing; the 39 papers that were delivered; a concisely-edited account of the discussion that followed each paper; and two appendices that list alphabetically the 217 registrants at the symposium and the 79 organizations they represented.

The papers, mostly by Britons, are grouped under eight major headings. These headings and the number of papers under each are: British Machines (8); Programming (4); Design (4); The Utilization of Computing Machines—Part I (4) and Part II (4); Circuitry and Hardware (6); Servicing and Maintenance (4); Medium-Size Digital Computing Machines (5).

These proceedings will prove of value to anyone interested in any phase of digital computing. The control or computing engineer will find especially profitable the section on "British Machines", which consists of detailed accounts of the major British large-scale digital computers, and the section on "Medium Size Digital Computing Machines".

. . . on English Feedback Analysis . . .

Linear Feedback Analysis. *J. G. Thomason, Radar Research Establishment, Malvern, England, 355 pp. Published by Pergamon Press Limited, Maxwell House, Marylebone Road, London, N.W.1. 55 shillings. U. S. A. edition published by Mc.Graw-Hill Book Company, Inc., 330 W. 42nd Street, New York 36, N. Y., 1955. $8.50.*

The purpose and origin of this book are explained in the author's statement: "The material in this book is intended to provide an analytical background for the young science (or engineering) graduate working in electronics or servomechanism research . . . it is hoped that the book will take the place of supplementary lectures on circuit analysis theory which may not be so widely available as would be desirable. . . . I have drawn heavily on R.R.E. lectures, seminars, and Journal articles in preparing this material."

The author's place of employment and his remark printed above account for the bent of the text. Although it is an account of basic theory common to feedback systems in general, employment and illustrations of this theory is focused largely on vacuum-tube amplifiers, particularly as used in radar and associated systems. An indication of the relative emphasis on the topics covered is provided by the eleven chapter headings and corresponding page numbers. The chapters are: 1. Steady-State Circuit Analysis (1-26); 2. The Laplace Transformation in Circuit Analysis (27-49); 3. Illustration of the Transformation Technique (50-77); 4. Introduction to Feedback Circuits (78-98); 5. Amplifying Stage Design (99-118); 6. The Stability of Feedback Systems (119-159); 7. Gain-Phase Analysis (160-196); 8. Stabilization Techniques (197-241); 9. Illustrative Feedback Amplifiers (242-289); 10. Feedback Integrators and Differentiators (290-327); and 11. Stabilized Power Supplies (328-344). A table of 34 Laplace transforms, a set of English tube characteristics, and a list of 31 pertinent "References" complete the volume.

Chapters 1, 2, and 3, respectively, deal with these facets of network analysis: setting up the governing differential equations and effecting steady-state solutions to sinusoidal inputs by use of complex-number algebra with both mesh and nodal approaches; an outline of certain elements of Laplace transform theory; and illustrative solution of simple networks by Laplace theory. Chapter 4 applies basic feedback theory to vacuum-tube amplifiers, while Chapter 5 uses this theory in design of amplifier stages, with emphasis on techniques (such as biasing and decoupling) which are used in discussion of stabilization in later chapters. Chapter 6 essentially consists of derivation and illustration of use of Nyquist's criterion. Chapter 7, stemming largely from similar content in Bode's text, is devoted to derivation and illustration of use of basic equations relating the gain and phase characteristics of minimum-phase linear systems. The last four chapters principally contain descriptions of varied illustrative designs. "The circuits shown are tested and mostly representative of present-day practice," the author says, "but are not put forward as the ultimate in design."

Present-day automatic feedback con-

trol system design commonly entails design of a number of feedback amplifiers (and associated equipment) as important components of the general system. Accordingly, this book includes much of interest to anyone concerned with feedback control systems, regardless of his particular specialization. With this idea in mind, the reviewer recommends this excellent text to the earnest attention of those for whom it was written—the practicing engineers who desire to attain through self-study a knowledge of modern feedback amplifier theory and practice.

. . . And on an Automatic Production Symposium

PROCEEDINGS: SYMPOSIUM ON AUTOMATIC PRODUCTION OF ELECTRONIC EQUIPMENT. 119 pp. Published by Stanford University Press, Stanford, California. $4.00

This volume contains the papers and the panel discussion of the Symposium on Automatic Production of Electronic Equipment, held in San Francisco April 19-20, 1954, under the sponsorship of the Stanford Research Institute and the United States Air Force.

It contains the keynote address, "Automation for Survival", and fifteen talks delivered at sessions on "General Aspects of Automation", "Product Design, Construction Techniques, Materials and Components", and "Design of Automatic Production Lines".

This book should prove of interest to all control engineers in automatic production work, whether or not they are concerned with electronic components. For example, although the paper by J. Y. Kaplan, "Techniques for Adopting Present Machine Tools for Automation", describes a particular project, the conceptual ideas therein should suggest numerous other applications in machine-tool control.

Thomas J. Higgins
Professor of Electrical Engineering
University of Wisconsin

Data Processing Study

PRODUCTION CONTROL THROUGH ELECTRONIC DATA PROCESSING: A CASE STUDY. 52 pp. Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C. $1.50

This case study, PB111580, covers

production control through electronic data processing. It was prepared especially for management and requires no previous knowledge of electronic computers. Through the case study method the kinds of clerical operations that data processing machines can be expected to perform are described and illustrated.

The report first considers some major principles involved in applying these new machines to business operations; then, to illustrate the application of these principles, it describes an in-plant research study and the electronic data processing system that was prepared as a result.

Another British Import —on Hydraulic Control

HYDRAULIC OPERATION AND CONTROL OF MACHINES. *By Ian McNeil. $5\frac{1}{2}$ x $8\frac{1}{2}$ in., 324 pp. Published by The Roland Press Co., New York.* $7.50.

This highly readable book, imported from England, emphasizes the practical aspects of fluid pressure. The pages that do cover basic hydraulic relationships serve to round out and introduce the ensuing chapters on transmitting hydraulic power and controlling mechanical motion.

Before introducing the many applications of hydraulic equipment, the author devotes several chapters to individual machines and to the problems normally encountered in their use. Among the former: hydraulic fluids, and seals, packing, pipes, and pipe couplings.

Applications covered include: power transmission, forging and extrusion machines, machine tools, mining and agriculture, and marine and aircraft uses of hydraulics. There is an interesting write-up of the Denny-Brown ship stabilizer that has been installed on several British vessels. While the terminology is British and the examples concern applications of British equipment, the American reader will have no difficulty in converting the context to his own vernacular.

WHAT'S AHEAD: MEETINGS

OCTOBER

Armour Research Foundation, Conference on Computer Applications, Illinois Institute of Technology, Chicago, Ill. Oct. 24-25

American Standards Association and National Bureau of Standards, Sixth Annual Conference on Standards (includes tour of National Bureau of Standards), Sheraton Park Hotel, Washington, D. C. Oct. 24-26

Instrument Society of America, Philadelphia Section, Symposium on "Automatic Control Loops–Electronic or Pneumatic?" Penn Sherwood Hotel, Philadelphia. Oct.28-29

The East Coast Conference on Aeronautical and Navigational Electronics, Emerson and Lord Baltimore Hotels, Baltimore, Md. Oct. 31-Nov. 1

NOVEMBER

Stanford Research Institute, World Symposium on Applied Solar Energy, Westward Ho Hotel, Phoenix, Arizona. Nov. 1-5

Institute of Radio Engineers, Association for Computing Machinery, and American Institute of Electrical Engineers, Eastern Joint Computer Conference and Exhibition, Hotel Statler, Boston. Nov. 7-9

American Society of Mechanical Engineers, Diamond Jubilee Annual Meeting, Conrad Hilton and Sheraton-Blackstone Hotels, Chicago, Ill. Nov. 13-18

Second International Automation Exposition, Navy Pier, Chicago, Ill. Nov. 14-17

Institute of Radio Engineers, Professional Group on Instrumentation, Conference and Exhibition on "Data Handling", Atlanta Biltmore Hotel, Atlanta, Ga. Nov. 28-30

DECEMBER

Engineers Joint Council, International Atomic Exposition, (10-16), and Nuclear Engineering and Science Congress, Public Auditorium, Cleveland, Ohio. Dec. 12-16

EMPLOYMENT OPPORTUNITIES

NATIONAL COVERAGE

The advertisements in this section include all employment opportunities—executive, management, technical, selling, office, skilled, manual, etc.

— RATES —

DISPLAYED: The advertising rate is $14.00 per inch for all advertising appearing on other than a contract basis. Contract rates quoted on request.

An advertising inch is measured 7/8" vertically on a column—3 columns—30 inches to a page.

Subject to Agency Commission.

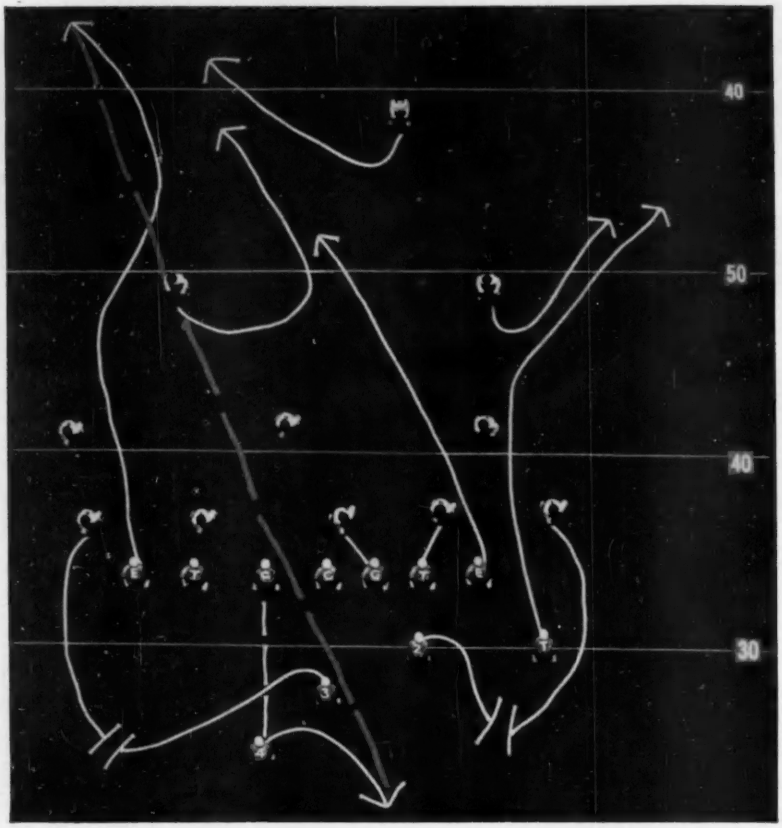
UNDISPLAYED: $1.50 per line, minimum 3 lines. To figure advance payment count 5 average words as a line.

Box numbers—counts as 1 line.

Discount of 10% if full payment is made in advance for 4 consecutive insertions.

Subject to Agency Commission.

Send New Ads to CONTROL ENGINEERING, 330 W 42nd St., N. Y. 36, N. Y. for December Issue Closing November 27th.



aerial attack

Q: What has *this* to do with the aircraft industry —and you?

A: It may have plenty to do with both. Here's how:

Football teams are judged by scoring ability in top competition—teamwork, form, ability, strategy, class. So, too, are aircraft companies.

Martin has created one of the finest engineering teams in the whole world of aviation. And under the new Martin concept of design and development by team operation, every engineering problem—from today's experimental contract to the frontier problems of the future—is the target for a coordinated "aerial attack" by a top-flight team of specialists.

Result: Martin's team operation technique has opened up important opportunities for young creative engineers.

Contact J. M. Hollyday, Dept. C-11, The Martin Company, Baltimore 3, Maryland.

MARTIN
BALTIMORE

ENGINEERS

PERMANENT
CREATIVE OPPORTUNITIES
FOR

ELECTRICAL
AND
MECHANICAL ENGINEERS
AT

Bendix

Immediate openings for . . . .

SENIOR COMPUTER ENGINEER

At least five years experience with analog computers with control applications. A degree in electrical engineering, or math and physics required. Activity is in the field of aircraft and missile power plant controls, including gas turbine, ram jet, and rocket types. Work will be with hydra-mechanical pneumatic and electrical components. The fuel metering research facility includes an analog computer and jet engine simulators.

MAGNETIC AMPLIFIER SYSTEMS ENGINEER

Electrical engineer supervisory capacity on research and development of magnetic amplifier circuitry, control systems, and component design and testing, supervising other engineers and technicians.

COMPUTER ENGINEER

Graduate engineers thoroughly qualified as a digital computer programmer, capable of handling engineering and production calculations, to train present personnel in preparation of data for computer applications. Set up new applications. Work with complex dynamics and control problems characteristic of the jet engine fuel system and landing gear fields.

LIQUID PROPELLANT ROCKET CONTROLS ENGINEER

Mechanical or electrical engineer to supervise the research and development of liquid propellant rocket controls, systems design, component design, development and testing.

The salary of these positions will be determined by your ability and experience.

Send detailed resume listing education, engineering experience, and salary requirement to:

TECHNICAL EMPLOYMENT DEPARTMENT
BENDIX PRODUCTS DIVISION OF
BENDIX AVIATION CORPORATION
401 North Bendix Drive
South Bend 20, Indiana

We guarantee you an immediate reply—

ENGINEERS

OPPORTUNITIES IN DESIGN & DEVELOPMENT

SENIOR ENGINEERS For gyro system development projects, and electrical engineers with experience in design and development of circuitry for airborne gyro mechanisms, servo mechanisms and their related systems.

ELECTRONIC ENGINEERS To work on autopilot systems development & design or investigations, evaluation and testing of systems involving interacting servo loops, servo sub-systems, circuitry including audio frequency amplifiers, magnetic amplifiers, and switching systems.

DESIGN ENGINEERS For design and layout of gyro instrument components for aircraft flight control systems. Will consider top-grade machine designers experienced on intricate precision mechanisms with engineering degree.

ENGINEERS AIR DATA Development engineers for master air data systems to be designed specifically for inputs. Requires knowledge of altitude, altitude rate, mach, air speed sensors and instrument servo theory and practice.

We are located in Grand Rapids, Mich., a good clean & modern city of 200,000, where recreational & cultural opportunities are the finest.

Competitive salaries. Generous moving allowance. All replies held confidential.

Interviews arranged at company expense with selected applicants.

Send complete resumes to:
Personnel Manager

LEAR, INC.
110 Ionia Ave. N. W.
Grand Rapids, Mich.

SYSTEMS SYNTHESIS ENGINEER

Guided Missiles Field . . .

A creative and responsible position with General Electric, a company noted for maintaining a stimulating environment for engineers.

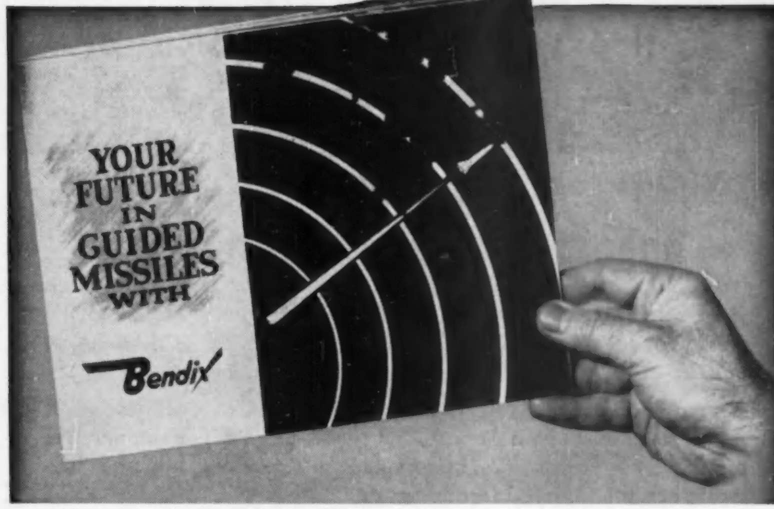
Progress in the development of guided missiles has created an opportunity for an experienced engineer capable of applying a broad viewpoint to the problems of weapons systems and of using a creative approach to synthesize systems meeting military requirements.

At least ten to fifteen years experience is desirable, and should include a background in servo systems, radar systems, guidance systems, etc. An engineer with three to seven years experience will also be considered for work in carrying out the more detailed portions of the systems synthesis function.

This is an unusual opportunity to join an outstanding scientific staff in work of major importance for the future.

Send complete resume to
BR. JAMES HEVELIN
Special Defense Projects Dept.

GENERAL ELECTRIC
2900 CAMPBELL AVENUE
SCHENECTADY, N. Y.



If you are interested in guided missiles this book will interest you.
Here is one of the most complete guides to job opportunities in the guided missile field yet published. In this book, you will find not only a complete outline of the objectives and accomplishments of the Bendix Guided Missile Section, but also a detailed background of the functions of the various engineering groups such as system analysis, guidance, telemetering, steering intelligence, component evaluation, missile testing, environmental testing, test equipment design, reliability, propulsion, and other important engineering operations. Send for your free copy today.

23 challenging opportunities in the newest and fastest growing branch of the aviation industry are now open!

Bendix job opportunities in guided missiles range from top senior engineers to assistant engineers, junior engineers, technicians, and a score of other assignments.

Qualified men are given real job responsibility with Bendix and grow with the development of what is not only the nation's most important weapon system, but a project that will undoubtedly lead to new and important long-range commercial applications.

And at Bendix you will be associated with top missile authorities and have at your command unexcelled engineering and manufacturing facilities.

If you are interested in a future in guided missiles, the first step is to fill out the coupon and mail it to us today.

Missile Section, Employment Department N
Bendix Products Division, Bendix Aviation Corporation
401 North Bendix Drive, South Bend, Indiana

Please send me a copy of the book "Your Future in Guided Missiles."

*Name*__________
*Address*__________
*City*__________
*State*__________

Engineer, Engineering Physicist or Physicist for Permanent Position with GOODYEAR ATOMIC CORPORATION

Near Portsmouth, Ohio, this plant is the newest addition to the AEC Gaseous Diffusion program for production of fissionable materials.

Senior Engineer and/or Physicist with extensive background in fundamentals of both Laboratory research and development is needed for new activities in computors, digital and analog, automatic controls. Servo-Mechanism and transistors.

Send experience resume and salary requirements. Address:

D. G. Barkett
Supervisor, Technical Recruitment
GOODYEAR ATOMIC CORPORATION
Box 628, Portsmouth, Ohio

BELL Aircraft CORP.

TEXAS DIVISION

Positions Open For:

SERVO-ENGINEERS

Interested in creative design responsibilities for helicopter automatic controls. Key positions for graduate engineers with experience in design and development of aircraft automatic control systems, including circuitry design and analogue computer simulation systems and component analysis.

ELECTRICAL ENGINEERS

For wide variety of instrumentation projects on newly developed rotary winged aircraft.

WRITE:

MANAGER, ENGINEERING PERSONNEL
BELL AIRCRAFT CORPORATION
FORT WORTH 1, TEXAS

UNUSUAL CREATIVE FREEDOM at Bendix AVIATION RESEARCH LABORATORIES DIV.

• The center of advanced development activities for the Bendix Aviation Corporation offering excellent opportunities in design, research and development.

SYSTEMS ENGINEERS
To coordinate and supervise a group of engineers and mathematicians in systems analysis and design.

MATHEMATICIANS
Evaluation of servo control and guidance systems and components of a system Analysis of systems and applications.

MACHINE DESIGNERS
Design of automatic machine tools, machine tool hydraulic servos, and digitally controlled tools.

CONTROLS ENGINEERS
Analyse and synthesize control system and design, develop and package such systems.

COMPUTER ENGINEERS
Development of special purpose digital and analog computers for process and business applications.

MICROWAVE SPECIALISTS
Research and development in advanced microwave techniques.

MECHANICAL ENGINEERS
Develop mechanical and hydraulic components for servo controls. Systems engineering and dynamic analysis of numerically controlled machine tools.

• **Staff will participate in the initial exploration of new fields and the development of new commercial products.**

All replies confidential—send brief resume to:

DIRECTOR OF PERSONNEL
BENDIX AVIATION CORPORATION
RESEARCH LABORATORIES DIVISION
4855 Fourth Avenue • Detroit 1, Mich.

ENGINEER
M. E. or E. E.
DIGITAL COMPUTER DEVELOPMENT

Excellent opportunity to join an expanding, stable company, with an outstanding position in the precision electronic control industry.

Opening now available for an engineer able to assume responsibility for the development of complete systems for fire control and guidance, or major portions of such systems. Work will include research and development in the field of complex analog or digital computers.

A degree in electrical or mechanical engineering is required or the equivalent in experience. Send resume in confidence to:

Technical Personnel Dept. 2-500
ARMA
Division American Bosch Arma Corp.
Roosevelt Field, Garden City
Long Island, N. Y.

An employment advertisement in this EMPLOYMENT OPPORTUNITIES section will help you find the engineers you need. It's an inexpensive, time saving method of selecting competent personnel for every engineering job in the control engineering field.

Farnsworth IT&T has a future for ELECTRONIC ENGINEERS

in these specialized fields

MISSILES

Research, systems analysis, development, and design in guidance and control systems, systems component equipment, and systems operational test equipment.

TEST EQUIPMENT

Research, development, and design in Guided Missile operational test equipment systems and systems component equipment.

MICROWAVES

Systems analysis, development, and design in microwave circuitry and components for missile guidance systems, radar systems, and systems test equipment.

RADAR

Study, analysis, development, and design in highly advanced radar techniques, and electronic countermeasures.

ANTENNAS

Research, development, and design of airborne antennas in low-frequency, UHF, and microwave regions for missiles, radar, and countermeasures equipment.

PACKAGING

Encapsulation and subminiaturization design for reliability and produceability in missile guidance and control equipment systems, airborne radar systems, operational systems test equipment, closed-loop TV systems, etc.

Career-minded men with several years specialized experience, and preferably with advanced degrees, are invited to join our rapidly expanding programs in industrial and military electronics.

Address inquiries to:

Technical Employment Manager

FARNSWORTH ELECTRONICS CO.,
Fort Wayne, Indiana
A division of International Telephone and Telegraph Corp.

2 *POSITIONS*

WITH ADVANCED
GUIDED MISSILES PROGRAM

Analytical, Mathematical, Statistical or Systems Background

Two responsible positions with a major company, located in Upper New York State are now open. Work is in the increasingly important field of guided missiles.

For man with analytical-systems experience or background, an opportunity to assume responsibility for establishing over-all feasibility and composition of atomic weapons fusing and arming systems. Systems must meet basic requirements established by Military Characteristics, including cursory evaluation, definition of function, selection of components to make up complete systems and establishment of general requirements and limitations which sub-systems and components must meet in satisfying overall system requirements.

For man with analytical-mathematical background or experience work involving statistical and analytical studies to establish feasibility, accuracies, dud and premature probabilities applicable to fusing and arming systems and components thereof for missile atomic weapons.

Exceptional working conditions, full facilities, extensive program of benefits including technical courses.

Please Send Complete Resume to

P-8013, Control Engineering
330 W. 42 St., N. Y. 36, N. Y.

NEED ENGINEERS?

An employment advertisement in this EMPLOYMENT OPPORTUNITIES section will help you find the engineers you need. It's an inexpensive, time saving method of selecting competent personnel for every engineering job in the control engineering field. The selective circulation of CONTROL ENGINEERING offers you an opportunity to choose the best qualified men available.

ENGINEERS Electronic • Mechanical DESIGNERS • DRAFTSMEN

How do you Measure success?

Some measure success only by money; others by the enjoyment they get out of their work. But the true measure of success is a combination of both *plus* the knowledge that your efforts are recognized and appreciated.

Melpar engineers find diversity and opportunity for professional growth; they enjoy being part of a highly creative staff without losing their individuality; and they benefit from Melpar's completely integrated facilities for system responsibility from design concept through production.

To learn how Melpar measures up to your own standards send complete resume to

- Network Theory
- Systems Evaluation
- Automation
- Microwave Technique
- UHF, VHF or SHF Receivers
- Analog Computers
- Digital Computers
- Magnetic Tape Handling Equipment
- Radar and Countermeasures
- Packaging Electronic Equipment
- Pulse Circuitry
- Microwave Filters
- Flight Simulators
- Servomechanisms
- Subminiaturization
- Electro-Mechanical Design
- Quality Control & Test Engineers

Technical Personnel Representative

melpar, inc.

Subsidiary of Westinghouse Air Brake Co.

3000 Arlington Blvd., Dept. CE-15 Falls Church, Va.
11 Galen Street, Watertown, Mass. • 99 First St., Cambridge, Mass.

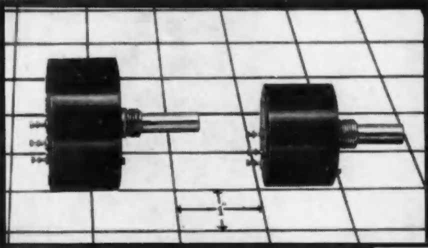
Advertising In This Issue

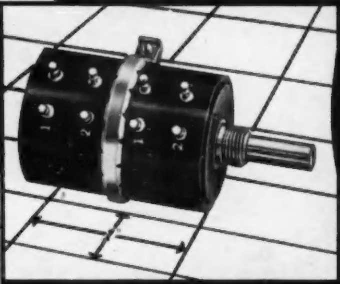
® TIC **low cost**

PRECISION POTENTIOMETERS

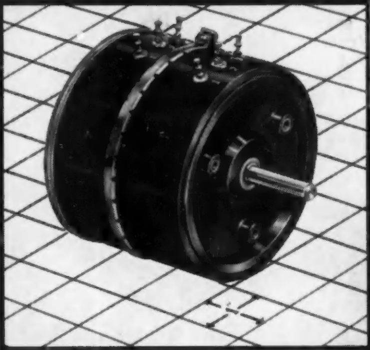
for **AUTOMATION** and **INDUSTRIAL**

APPLICATIONS





The P-Series have been designed to meet the growing demand for economical precision potentiometers used in commercial instrumentation. These units retain many of the precision features developed for stringent military requirements.



P-Series Features:

- TIC Standards of Accuracy
- Low Noise
- Long Life
- Low Torque
- Linear and nonlinear functions
- Minimized Distributed Capacity
- Excellent Frequency Response
- High Stability
- Single or Ganged Assemblies

SPECIFICATIONS

ELECTRICAL	P 3	P 1⅝	P 1¼
Resistance Range	100-200 KΩ	100-150 KΩ	100-100 KΩ
Independent Linearity	±0.5% std. to ±0.15% spec.	±0.75% std. to ± 0.25% spec.	±2.0% std. to ±0.5% spec.
Winding Angle	320° ±3° std to ±1° spec.	315° ±3° std to ±1° spec.	315° ±5° std. to ±2° spec.
Power Rating	8 watts @ 25°C	4 watts @ 25°C	2.5 watts @ 25°C
Taps	Available with 10° minimum separation, located within ±1° standard to ±0.5° special		
Ambient Temp Range	−55°C to +80°	−55°C to +80°	−55°C to +80°
MECHANICAL			
Mounting	Tapped Hole	Threaded Bushing	Threaded Bushing
Housing	Bakelite base with aluminum cover	Bakelite base and cover	Bakelite base and cover
Terminals (Gold flashed on silver plate)	Side of base only	Side or cover optional where not ganged	Side or cover optional where not ganged
Bearings	Precision-bored	phosphor-bronze	sleeve-type
Mechanical Rotation	360° std. Mechanical stops available.		

A brochure and full details yours upon request.

TECHNOLOGY INSTRUMENT CORP.

523 MAIN ST., ACTON, MASS. COlonial 3-7711
West Coast Mail Address P.O. Box 3941 North Hollywood, Calif. POplar 5-8620